INVESTIGATION OF COAL BURNING EQUIPMENT DESIGNED TO BURN UTAH COAL WITHOUT THE EMISSION OF SMOKE.

by

OTTO DUKE

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Approved b[redacted]

TABLE OF CONTENTS.

LIST OF ILLUSTRATIONS

INVESTIGATION OF COAL BURNING EQUIPMENT DESIGNED TO BURN UTAH COAL WITHOUT THE EMISSION OF SMOKE.

I. GENERAL STATEMENT CONCERNING INVESTIGATIONS.

1. The Cooperative Agreement:-

At the last session of the Utah State Legislature a bill was passed appropriating $10,000.00 to the University of Utah for Coal Research. The bill, however, carried the reservation that the State money would be available when an equal amount was made available from some other source to match this appropriation.

The Utah Coal Producers Association agreed to match this money, at least in part, in order to start investigations which would develop better coal burning methods and better equipment, so that coal as a fuel can more successfully meet the competition of other fuels now on the market. A Department of Coal Research was then organized at the University of Utah under the direction of Dr. D. A. Lyon, Director of the Utah Engineering Experiment Station. Prof. E. H. Beckstrand, head of the Mechanical Engineering Dept., and Dr. Thomas B. Brighton, head of the Department of Metallurgy, were placed as Senior Investigators, and the writer, Otto Duke, was employed as Research Fellow to conduct the investigations in cooperation with the senior investigators and the Utah Coal Producers Association.

2. Importance of the Coal Industry.

Coal is one of Utah's greatest natural resources. The United States geological survey estimates that approximately one-sixth of the area of the state is under-laid with veins of workable thickness and they estimate the unmined reserve to be 196 billion tons. The average annual production of coal in Utah during the last ten years is about 5,000,000 tons. The average number of employees in the coal industry is a little in excess of 5,000, and the annual payroll is about $7,500,000.00, although the industry furnishes the chief means of livelihood of approximately 25,000 men, women, and children in the state of Utah. In addition to the wages paid, the coal industry spends in the neighborhood of $2,500,000.00 annually for supplies; $750,000.00 for power and taxes, and provides about $15,000,000.00 a year in freight revenue for western railroads. (The above figures are taken from "Utah and its Mineral Wealth" published by the Salt Lake City Chamber of Commerce 1930."

3. Problems of the Coal Industry.

It is readily seen then, that the coal industry is a great source of wealth, and for the state to continue in its march of progress, the consumption of coal should, if possible, be increased. Up until very recently, the consumption of coal automatically increased with increasing population and expanding industry, but at present there are two important factors tending to diminish the use of coal. One of these is the competition of Natural Gas, which was brought to this vicinity in 1929 through a large pipe line from the wells in Southwestern Wyoming. The other factor is the growing public sentiment against the cloud of smoke which hangs over our cities during the winter months, and which is blamed, of course, to the burning of coal.

The tests outlined in the following pages, together with many other successful demonstrations, prove conclusively that high volatile bituminous coal can be burned efficiently and without smoke when the fundamental principles of combustion are applied. These demonstrations convince us that the smoke nuisance we are faced with today is not the fault of our coal, but the fault of the equipment we burn it in.

4. Weakness in Present Coal Burning Equipment.

We need only to examine cook stoves, heating stoves, and heating furnaces and note the accumulation of soot to be convinced that the coal is not being completely burned in our present equipment. If these stoves and furnaces were designed at all, they were designed for a low volatile and not for a high volatile coal such as we have in Utah. Almost without an exception, the combustion chamber is so arranged that the volatile products are cooled down below the ignition temperature before they have had time to burn. This liberates solid carbon which accumulates as soot, cutting down the rate of heat transfer, stopping up the gas passages and polutting the atmosphere. Burning coal in such devices represents a great economic waste, for the gases and solid carbon which make up the smoke are combustible and carry away a goodly portion of the heating value of the fuel.

5. Mechanism of Combustion of Bituminous Coal

The combustion of coal is a complex phenomenon and only such phases as seem useful in building up a picture which will explain our tests, will be given here. As the coal is heated, the volatile matter is liberated. This liberation is a more or less gradual process, since a lump of coal is a comparatively poor conductor of heat. The rate of liberation will depend on the size of coal particles and the temperature surrounding them. These volatile products are composed of a great many compounds, mostly hydrocarbons.

The lighter, or gaseous, hydrocarbons are made up of from one to four carbon atoms per molecule, such as Methane CH_4, Ethylene C_2H_4, Ethane C_2H_6, etc. The heavier, or liquid hydrocarbons, have from five to 34 carbon atoms per molecule, such as Petane C_5H_{12}, Hexane C_6H_{14}, Decane $C_{10}H_{22}$ and on up to the heaviest paraffins such as Tetratricontane $C_{34}H_{70}$.

The lighter compounds such as Methane and Ethane seem to burn very rapidly, even faster than hydrogen or carbon monoxide. The heavier hydrocarbons, and especially the oils and tars first undergo a cracking process in which a lighter hydrocarbon plus free carbon is formed. There are also heavy hydrocarbons formed during cracking which are extremely hard to oxide and are deposited with the soot, giving it an oily appearance. Some of the hydrocarbons decompose thermally into carbon and hydrogen. The hydrogen ignites at a lower temperature than does the carbon and therefore burns first. If the temperature is not high enough and the mixture with oxygen not intimate enough, the carbon remains in the solid state, depositing as soot in the furnace and flue, or going out the chimney as smoke. In the oxidation of the coke left by the distillation of the volatile matter, it is believed that CO and CO_2 are formed simultaneously, the CO later reacting with additional oxygen to form CO_2.

Complete and instantaneous combustion of all the fuel to CO_2 and H_2O does not occur, therefore the furnace must be designed to furnish sufficient time, intimate mixing of fuel with oxygen and high enough temperature to completely burn all the fuel, volatile as well as solid.

6. Object of Investigation.

The object of these investigations has, therefore, been to run complete and accurate tests on equipment designed to give better combustion and find to what extent the smoke can be eliminated and the efficiency increased. A further object is to show that coal is the most economical fuel, that it can be burned efficiently and without smoke and that it can be burned automatically, giving all the comforts and conveniences attending thermostatic control.

7. Scope of Work.

The work accomplished this first year by the Coal Research Department consists of the following:

1. Running a series of tests on the boiler and furnace of the McDonald Chocolate Company, both before and after the installation of the McVay Combustion Chamber, showing the benefits gained by such installation.

2. Assisting the Board of Education and the U. S. Fuel Company in running a six weeks test on the heating plant at the East High School. This plant was run alternately one week on Natural Gas and a week on Coal to find the comparative efficiency and economy of the two fuels.

3. Setting up a furnace testing laboratory, collecting and making all the apparatus necessary for the tests.

4. Setting up and testing the first design of the Porter Furnace.

5. Designing a new furnace on the Porter principles and making complete drawings of all the parts for fabrication and erection.

6. Setting up a domestic hot air heating furnace and running a series of tests with hand firing and then a similar series with the firing done automatically by means of an underfeed stoker.

8. Proposed Program for the Immediate Future.

It is hoped that this work can be continued at least long enough to complete the following investigations:

1. Test the underfeed stoker to determine the characteristics with different air pressures and velocities.

2. Find the effect of sizing of the coal on the stoker operation.

3. Find the comparative burning properties of coal from the various Utah mines in the domestic stoker.

4. Run a series of tests on each of the stokers on the local market with the idea of finding their limitations and reliability, improving any defects found and giving an approval of the University and Coal Producers Association on the stoker as a satisfactory coal burning device.

5. Build a furnace of the Porter type according to our new design and give it a thorough test and demonstration.

6. Adapt one of these successful methods of burning coal to heating stoves and cook stoves.

II. DOMESTIC HOT AIR FURNACE HAND VS. STOKER FIRED.

1. Object of Tests.

The object of these tests has been to determine the actual operating characteristics of the domestic furnace, regarding smoke production, rate of heat release, flue gas analysis, heat losses, and efficiency. With these data for both hand and stoker fired we can then show the desirability of using the underfeed stoker for smoke elimination, economy of operation, and comforts of thermostatic control.

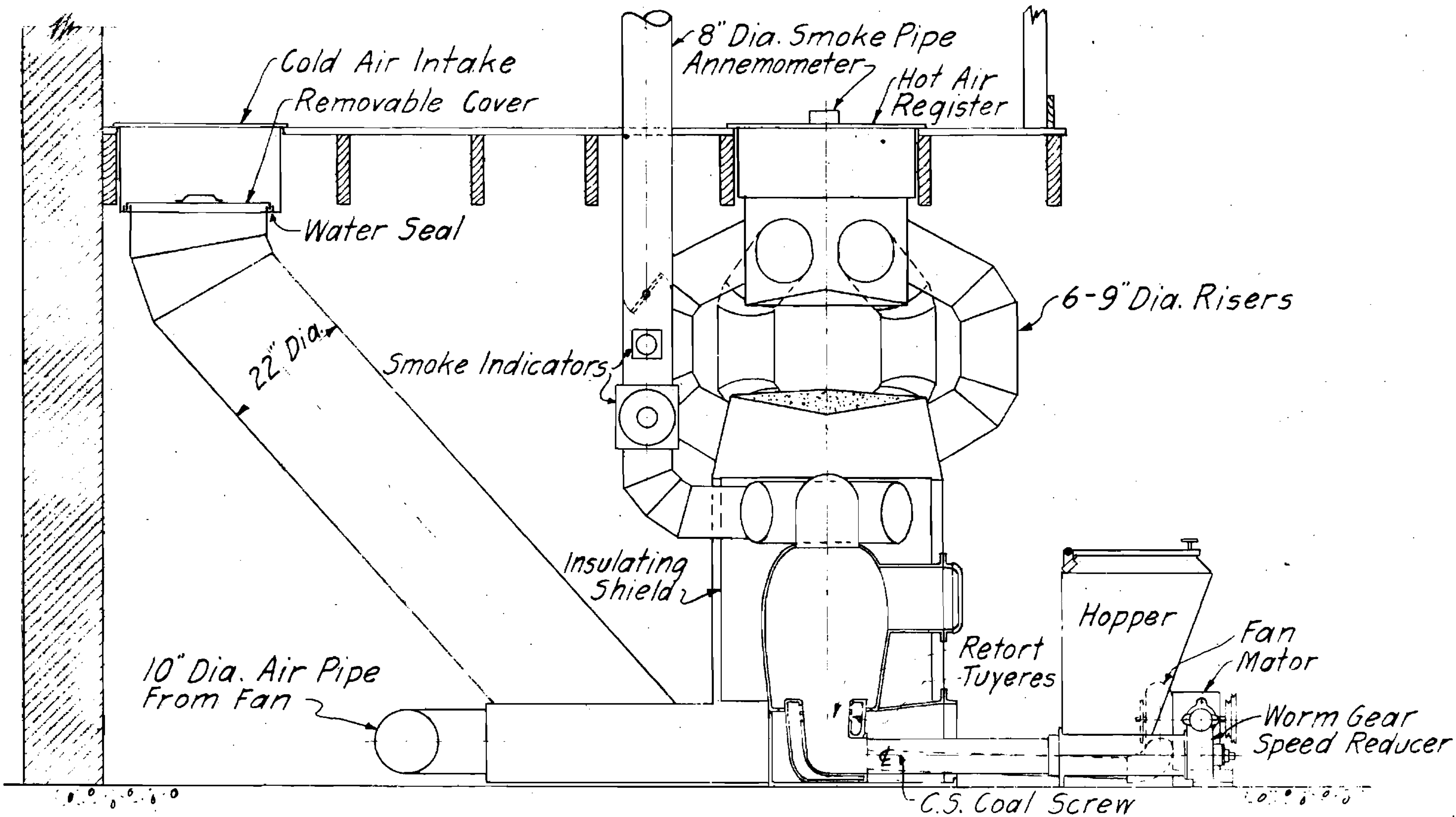
There were several reasons for choosing a domestic hot air furnace for these investigations, namely, (1) the residence smoke is now by far the greatest contributor to our smoky skies and a correction here is greatly needed, (2) the underfeed stoker shows very good possibilities in eliminating part of this smoke, (3) several stokers for domestic use have recently been developed locally and placed on the market, and the public, as well as the manufacturers are desirous of obtaining some accurate data on them and receiving the approval of some institution such as the Utah Engineering Experiment Station, and (4) the cost of setting up such a plant and making the necessary changes from time to time is much less than for an industrial furnace.

2. General Description of Plant.

The general arrangement of the furnace is shown in Fig. 1. The furnace was loaned to the University and set up by the Holland Furnace Company. It is one of their standard cast iron, circular radiator furnaces with 19" diameter fire pot. The volume of the combustion space above the hand fired grate is 4.16 cu. ft. and above the stoker retort is 4.01 cu. ft.

The hot air risers are brought together as shown to facilitate measuring the velocity and temperature of the air and still give a set-up corresponding to an ordinary residence. The circulating air may be drawn in, either through the large 22" dia. pipe or be blown through the 10" opening by the fan.

The stoker used was the Gray & Murdock Underfeed Domestic Stoker Size No. 1, manufactured in Salt Lake City. This stoker was chosen by a group of men representing the various stoker manufacturers in Salt Lake City, with the idea that the tests would continue on until the other stokers could be tested, The data found on this first



GENERAL ARRANGEMENT OF DOMESTIC HOT AIR FURNACE
Figure 1

Scale ½" = 1'-0"

stoker test could also be used by the other manufacturers especially regarding air pressures and velocities required, proper size of coal, burning characteristics of coal from different mines, etc.

The coal is fed from a hopper of 250 pounds capacity, by means of a cast steel screw, into the furnace retort. Air for combustion is supplied by a 9" diameter fan of the sirrocco type. The air is blown through a 3" diameter pipe into the outer ring of the retort and then through cast iron tuyeres into the bed of coals. The fan wheel is mounted on one end of the motor shaft and the coal screw is driven from the other. The fan inlet opening is provided with an adjustable cover. The coal screw is driven through a pair of pulleys and V-Belt to a double reduction worm gear. The pulleys have two grooves allowing two different speeds of the screw by merely shifting the belt.

The operation of the stoker is made automatic by means of time and temperature controls connected in the electrical circuit of the driving motor. A wall thermostat is provided which starts the motor when the temperature in the room falls below the temperature for which it is set and stops it again when the temperature has risen 3 or 4 degrees. A safety limit control is mounted with the thermostatic element in the furnace bonnet and prevents the overheating of the furnace. A time control is also provided which operates the stoker for a short period of time at predetermined intervals which prevents the fire from going out in mild weather. This control is operated by an electric clock.

3. Temperature Measurement.

Special care must be taken in measuring the temperature of hot air and gases or erroneous results will be obtained. The first precaution is to place the measuring instrument in a position such that the surrounding walls and objects will be as nearly as possible the same temperature as the gas. If, for instance, we should place a thermometer at a register face, it would receive heat by convection from the passing hot air, but would also give off more heat by radiation to the surrounding colder walls than it would receive. Hence the true temperature of the air would be hotter than was indicated. For this reason the temperature of the hot air was taken at a point in the riser at which the tip of the thermocouple could "see" neither the hot dome of the furnace nor the cold walls of the room. The flue gas temperature was taken at a similar place, besides having the smoke pipe and elbow covered with about 1 1/2 inches of plastic insulating material.

The temperatures at the various points were read by means of thermocouples and potentiometer indicator. There were two reasons for choosing this method instead of using mercury thermometers. First--the thermocouples are smaller diameter, hence have smaller radiation losses, and also are quicker to respond to temperature changes. Second--the temperature at the several locations can be read at a central position by means of one potentiometer and a set of switches. This makes it possible to take a set of readings much more quickly than if the observer had to move to several locations and read mercury thermometers.

The thermocouples were made of No. 20 gage wire, the ends of the two wires being twisted for two or three turns and then the tip fused in an oxy-acetylene flame. The two wires were then brought through a two-hole porcelain insulating tube to binding posts mounted on a small piece of transite. From here, insulated leads were run to the switchboard and cold junction box as shown in Fig. 2. For temperatures below 500 Deg. F. the thermocouples were made of Copper V.S. Constantan with copper and constantan leads running to the switchboard. For higher temperatures the thermocouples were made of Chromel VS Alumel wire with copper and constantan leads running to the switchboard. The wire as well as the potentiometer was obtained from The Leeds and Northrup Company, Philadelphia, who are recognized as makers of very high grade scientific apparatus.

The theory of this method of measuring temperature is as follows: If two wires of dissimilar metals are joined together at both ends, and one junction is heated to a higher temperature than the other, there is an electromotive force set up which will cause a current to flow thru the circuit. The magnitude of the electromotive force depends on the kinds of metals and the difference in temperature between the two junctions.

The potentiometer provides, first a means of securing a known variable potential, and second, suitable

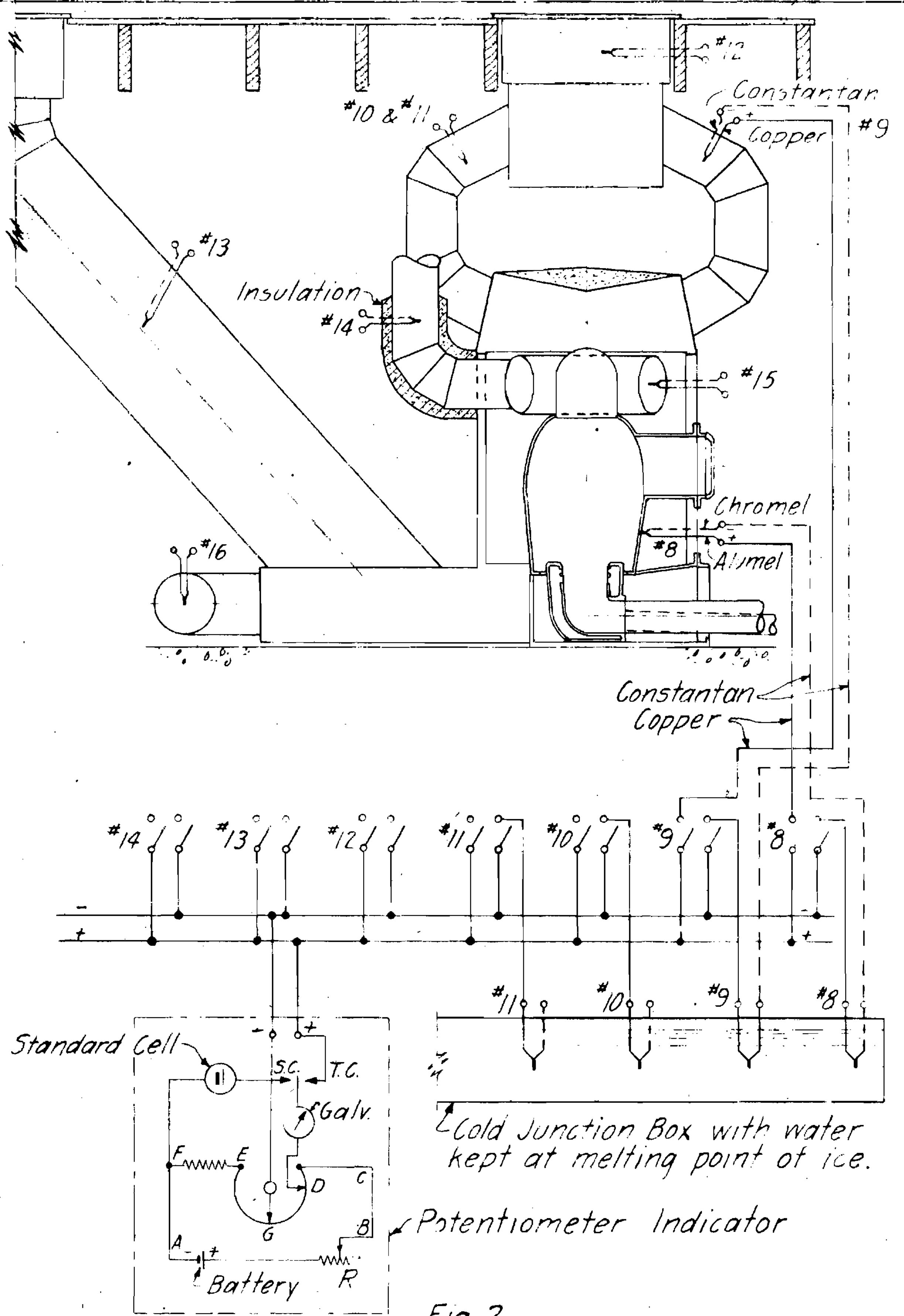


Fig. 2
DIAGRAM OF
TEMPERATURE MEASURING EQUIPMENT

electrical connections for opposing that potential to the unknown electromotive force of the thermocouple. The two are connected electrically so they oppose one another. So long as one is stronger than the other, a current will flow through the thermocouple; when the two are equal, no current will flow.

The wiring diagram shows the connections of the potentiometer and thermocouples. A current from the battery is constantly flowing through the main or so-called potentiometer circuit, BCDGEFA. The section DGE of this circuit is a slide wire, uniform in resistance. A current of known value is made to flow through the slide wire DGE which sets up a potential between D and E. The polarity of this is in opposition to the polarity of the electromotive force of the thermocouple which connects into the potentiometer at D and G. By moving G along the slide wire a point is found where the potential between D and G in the slide wire is just equal to the electromotive force of the thermocouple. A galvanometer in the thermocouple circuit indicates when the balance is reached, since at this point the galvanometer needle will show no deflection.

In order to always keep the same current flowing through the potentiometer circuit, a variable resistance R is provided and also a Weston type standard cell whose voltage is constant. The standard cell is connected to the potentiometer circuit at two points D and F by closing the key S.C. This puts the galvanometer in series with the standard cell. When it is desired to check the current flowing from the dry-cell through the main circuit, the key S.C. is closed and the variable resistance R is moved until the current flowing is such that, as it flows, through the slide wire DGE and the standard resistance EF the fall in potential between D and F is just equal to the voltage of the standard cell. At this time the galvanometer will indicate a balance in the same way as when it was used with the thermocouple. By this operation the current in the slide wire has been standardized. The standard cell is then disconnected and the thermocouple connected by pressing on the key T.C.

The potentiometer method is more accurate than other instruments which show a deflection corresponding to the E.M.F. of the thermocouple. With the latter type A current is flowing through the thermocouple circuit and may be influenced by the change in resistance of the leads due to change in temperature or may be in error due to a slight resistance drop at the terminals. With the potentiometer, however, there is no current flowing through the circuit and no chance of errors due to the above causes.

Each thermocouple was checked after installation to see that the connections were properly made and the temperature indication was correct. All the thermocouples were checked with a mercury thermometer at room temperature and at the boiling point of water. Two of the chromel-alumel couples were checked at the melting point of lead. In every case the millivolt reading was so very near the tabular value at the corresponding temperature that the tables furnished by the Leeds & Northrup Company were used to find the temperature corresponding to any millivolt reading.

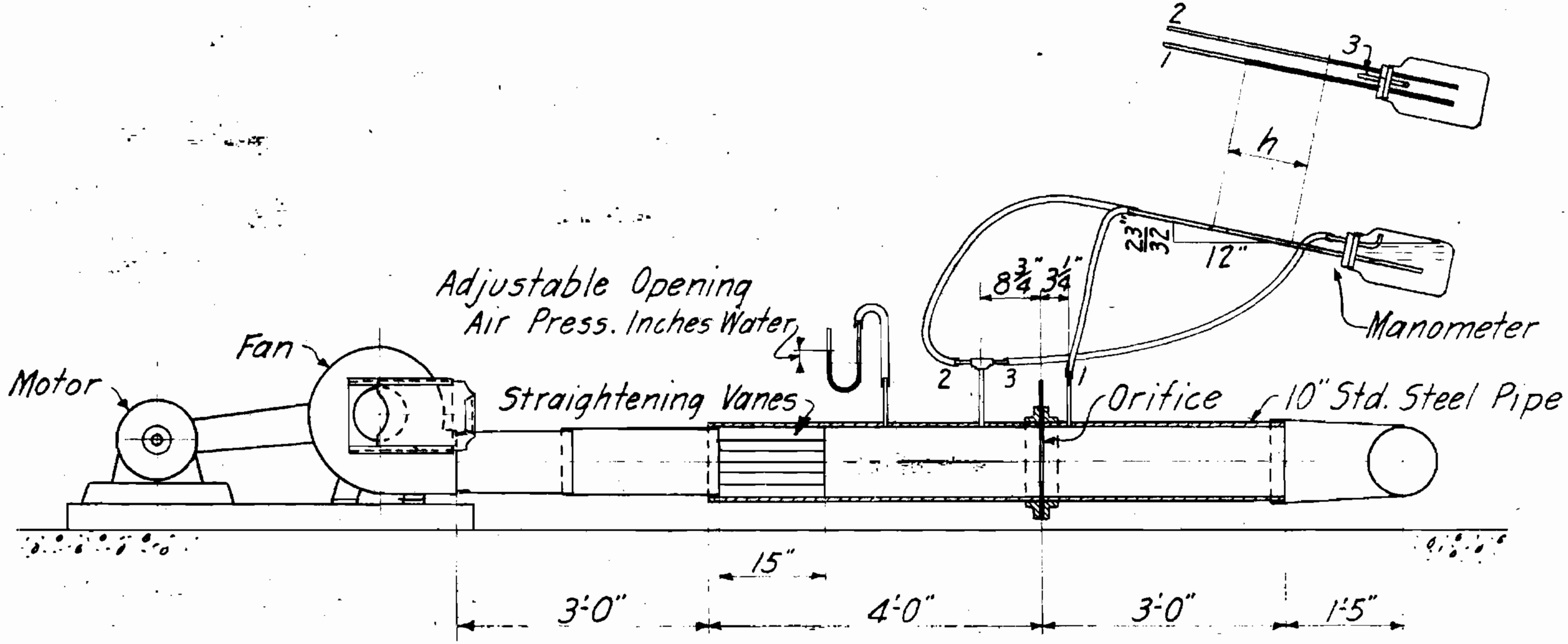


Figure 3
EQUIPMENT USED FOR MEASURING
QUANTITY OF AIR CIRCULATED

Scale 1/2" = 1'-0"

4. <u>Air Measurement.</u>

The weight of air circulated through the furnace was determined by blowing the air through an orifice mete r and thence into the bottom of the furnace casing. The arrangement of the furnace with air inlets is shown in Fig. 1 and the meter installation in Fig. 3.

In order that the quantity of air circulated would be as near as possible to the amount which would circulate under normal gravity conditions, a series of runs were made drawing air through the large inlet pipe and reading the annemometer placed over the hot air register. This gave us a relation between the annemometer reading and the corresponding register temperature.

The annemometer was a very high grade instrument, having a 4 inch diameter fan wheel, and a lever to start or stop the counting mechanism without stopping the fan wheel. Another lever allowed setting all the dials back to zero for the beginning of each test. A hole was cut in the center of the register with a small shelf to hold the annemometer so that it could only be set in one position and that position duplicated every time. When not in use the annemometer was removed from the register. When a reading was desired it was set in its place and allowed to run for several seconds to get to a constant speed. Then the pointer was released and allowed to run for exactly 60 seconds and stopped.

It was originally intended that the fan and orifice meter be used only to calibrate the annemometer and then the actual tests to be run with natural gravity flow through the furnace. It was found, however, that to calibrate the annemometer for the numerous quantities of air and various temperatures required, that the limited time at our disposal would not permit. Therefore, the fan opening was set so that at each rate of firing the temperature rise through the furnace and annemometer reading would be approximately the same as if natural circulation had been used. The weight of air circulated could be very accurately determined by means of the orifice and differential manometer.

The orifice was installed in accordance with the standard practice as recommended by the Republic Flow Meter Company and their value for the orifice coefficient was used. The results were checked and found to be almost identical with the method and coefficients as given by the

U. S. Bureau of Standards in the paper, "Discharge Coefficients of Square-edged Orifices for Measuring the Flow of Air," by H. S. Bean, E. Buckingham, P. S. Murphy, Journal of Research, March, 1929. The results were also checked by making a pitot tube survey across two diameters of the pipe with the tip of the tube 12 inches ahead of the orifice.

The development of the formula used in connection with the orifice is as follows:

Notation

D = Pipe Dia. = 10.136 inches
d = Orifice Dia. = 6.713 inches
r = Orifice ratio = d^2/D^2 = .4394
C" = Orifice Coefficient for 10" Pipe and r = .4394, = .2970
(Taken from Curves furnished by Republic Flow Meter Co.)
g = Acceleration of gravity = 32.2
H = Head in ft. of air
h" = Head in inches of water
h = Manometer difference inches of water measured along incline.
θ = Angle of inclination of Manometer = 3 deg. 25' 40"
w = Density of water = 62.31 lbs. per cu. ft. at 70 deg. F.
W = Density of air, lbs. per cu. ft. = 1.323 x P/T
t = Temperature of air Deg. F.
T = Absolute temperature of air = 460 + t
p = Pressure of air, inches of water above atmosphere
P = Absolute pressure of air, inches of mercury = barometer reading + p/13.6
Q = Air delivered in cu. ft. per sec.
Q" = Air delivered in lbs. per minute

Then

$$Q = C'' \frac{\pi}{4}\left(\frac{D}{12}\right)^2 \sqrt{2gH}$$

but $H = \frac{h''}{12} \times \frac{62.31}{W}$, and $h'' = h \sin \theta$

and $Q'' = 60WQ = 60C'' \frac{\pi}{4}\left(\frac{D}{12}\right)^2 \sqrt{\frac{2gh \sin\theta}{12} \times 62.31\ W}$

This reduces to

$$Q'' \quad 51.34\sqrt{\frac{hP}{T}}$$

for our particular conditions.

P,h and T are variables for each test but after the ~~variables for each test but after the~~ averages for the days run are obtained the formula is readily solved for wt. of air per minute. The variation of P, h and T were so slight on any test that the averages were made directly without averaging the square roots of the various observations.

5. Smoke Observations.

Since the elimination of smoke and soot was one of the main objects of our work, we took particular pains to work out a satisfactory method of measuring the quantities involved.

The arrangement of this part of the apparatus is shown in Fig. 4.

The upper smoke eye allowed us to look directly through the smoke pipe at a light globe on the opposite side. This would always show whether the flue gases were smoky or not, but an additional indicator was required to compare the density to some guide such as a Ringlemann Chart. The lower instrument furnishes such a guide. It will be noted from the drawing that the light from the rear globe shines through the smoke pipe and strikes the center ring of the chart. The outer part of the chart is illuminated from the globes on the near side of the pipe. The chart was ruled according to the standard for the Ringlemann Chart. The size of globes were chosen so that with no smoke in the main pipe, the center part of the chart was luminated to the same intensity as the clear section at the top of the outer part. Then as smoke started up the stack the intensity of the light striking the center ring was diminished and the color or relative brightness could be compared with one of the sections of the outer ruled part. Thus one could quickly look at the indicator and determine the number of the smoke.

6. Soot Determination and Flue Gas Analysis.

Figure 4 also shows the apparatus used for drawing a metered quantity of flue gas through an alundum filter thimble. The filter would catch the soot, fly ash or other solid particles in the sample and enable us to weigh the amount thus collected. After a sample had been weighed, the thimble would be placed in a muffle and the

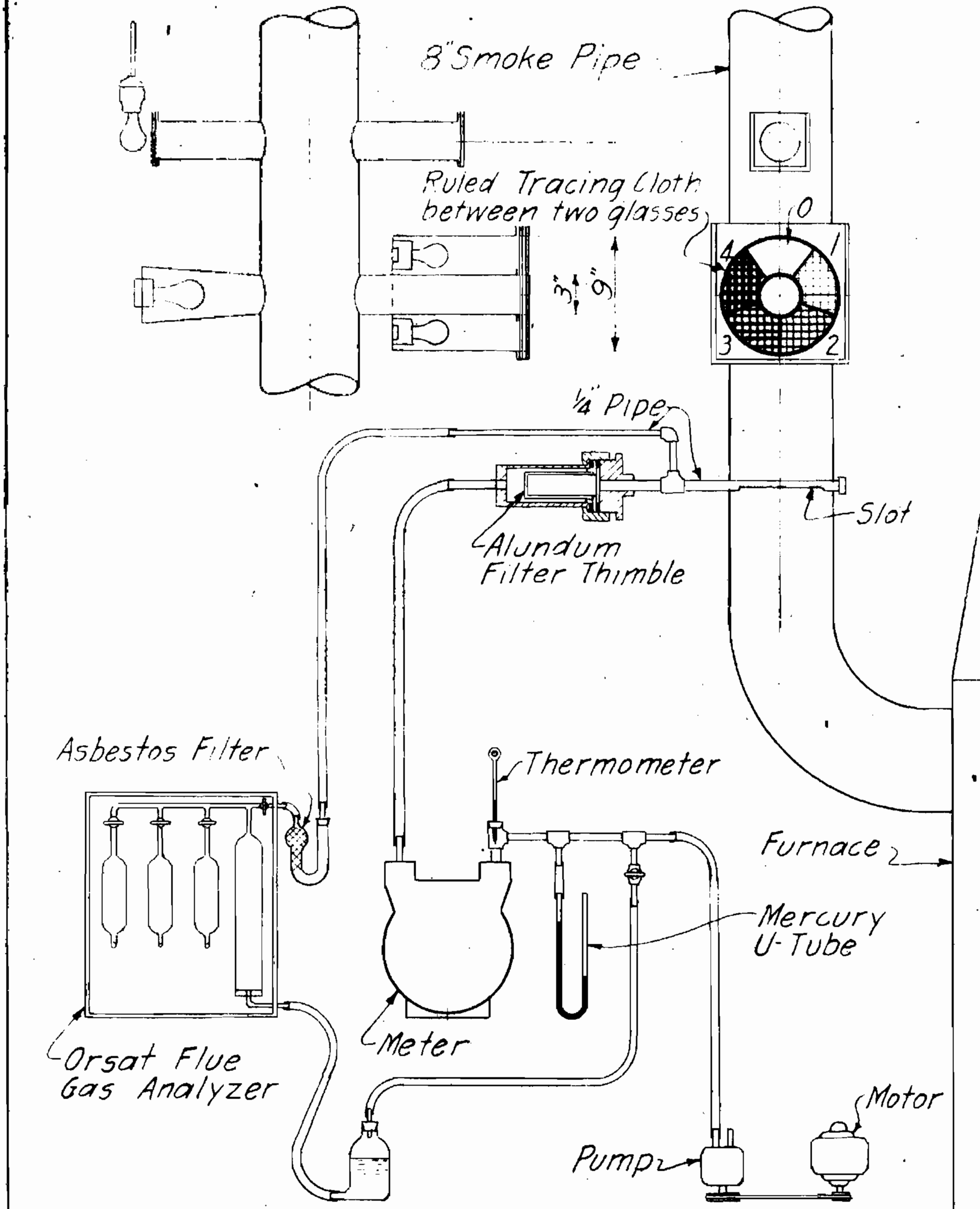


Figure 4

EQUIPMENT USED FOR
FLUE GAS ANALYSIS
SMOKE AND SOOT DETERMINATIONS

soot or carbon oxidized. The fly ash would remain in the thimble and was weighed. The fly ash was negligible on the hand-fired tests, but was a fairly good proportion of the total for the stoker-fired tests.

The suction pressure required to draw the sample through the filter would run from three to twelve inches of mercury. To avoid this high pressure on the Orsat instrument, we tapped the line ahead of the alundum thimble to draw our sample for flue gas analysis. A pressure this high would cause leaks around the cocks of the Orsat instrument and thus give erroneous readings.

7. OPeration of Furnace, Hand Fired.

On the hand fired tests, our aim was to fire the furnace as nearly as possible to the way we would in our home. The fire was allowed to burn low and then 20 to 30 pounds of coal was fired, using the alternate method, i.e. firing first to one side and then the other. The fire was not touched again until the firebed became well burned out and low, then another charge of coal was admitted. The test was ended, when after a period of 6 or 7 hours, the fuel bed became burned down to approximately the same conditions as at the beginning.

The fire was watched and readings taken on several occasions when starting up from a cold furnace with a wood kindled fire. The smoke given off was not appreciably more than when a charge of coal was thrown in on the live coals left from the previous firing.

The drafts were so set on the various tests that the rate of burning would remain nearly constant and also give a different rate for each of the tests.

8. Operation of the Furnace, Stoker Fired.

The stoker was operated a few days in order to determine the proper setting of the fan opening to maintain about an even bed of coals throughout the test. The operation seemed to be best if we carried a fairly deep bed of coals so the tests reported were so run. Our laboratory was too large a room to respond quickly to temperature changes so the furnace limit switch was used to control the stoker instead of the room thermostat. This was accomplished by setting the room thermostat at its upper limit which meant that its circuit would remain closed. The furnace limit would then control the stoker operation and it was found that it kept the temperature of the air in the risers between fairly narrow limits, as will be noted in the data. By setting the limit switch at a different temperature each day, a different rate of burning was secured.

The various controls were set and readings taken at various places until the operation seemed fairly constant and satisfactory, then the depth of fuel bed was carefully noted and the test begun. The fire was never stirred or touched during the test but if necessary the air was adjusted toward the end of the test in order to burn the fuel bed to the same size and condition as at the start. The stoker hopper was filled level full of coal at the beginning and the amount of coal burned during a test was taken as that required to again fill the hopper.

9.- DATA AND RESULTS OF TESTS
HOLLAND FURNACE-- HAND FIRED

Test Number	41	42
Date 1932	March 28	March 29
Size of Coal	Pea	Pea
PROXIMATE ANALYSIS OF COAL AS FIRED		
Volatile Matter - percent	44.55)	
Fixed Carbon "	43.29)	
Ash	6.93)	ditto
Sulphur	0.70)	
Moisture	4.53)	
Heating Value - B.t.u. per lb.	12384)	
FLUE GAS ANALYSIS		
Carbon Dioxide - CO_2 %	10.8	9.0
Oxygen - O_2	8.0	9.8
Carbon Monoxide - CO	0.6	0.5
Pounds of Air per lb. Coal	15.5	18.4
Percent Excess Air	60	90
PRESSURES		
Barometer - Inches Mercury	25.12	25.19
Draft at Smoke Collar - in water	.06	.10
Fan Pressure - inches water	.42	.45
Differential Pres. across orifice	11.85	14.00
TEMPERATURES - Deg. F.		
Room	75	80
Air Inlet	75	80
Hot Air Outlet - 3 Risers	204	256
Temperature rise-inlet to outlet	129	176
Flue Gas at Smoke Collar	696	930
C.I. Wall at Firepot	430	536
Gases in Circular Radiator	954	1122

43	44	45	46
March 30	March 31	April 1	April 4
Pea	Lump	Lump	Lump
	45.14)	)	
	43.01)	)	
ditto	7.26)	do.)	ditto
	.91)	)	
	3.68)	)	
	12920)	)	
7.3	6.2	7.2	9.5
12.1	13.7	12.3	9.5
0.3	0.0	0.2	0.4
22.7	27.5	23.2	17.8
130	170	140	80
25.54	25.67	25.42	25.29
.14	.12	.13	.13
.25	.30	.35	.50
9.25	8.92	8.90	15.80
77	78	84	83
77	78	84	83
174	160	180	228
97	82	96	145
486	452	546	898
284	240	207	288
742	712	759	1113

HAND FIRED TESTS, Cont'd.

Test Number	41	42	43	44	45	46
FLUE GAS SAMPLE						
Cu. Ft. Drawn		189.1	296.7	264.3	188.3	146.5
Aver. Suction Pres. in.Hg.		9.2	6.4	8.0	9.2	8.2
Aver. Temperature - Deg. C.		31.9	26.4	28.0	30.5	32.0
Weight of Soot - Grams		3.617	3.201	1.938	1.683	2.200
Lbs. soot in Chimney Gases per 100# coal		2.09	1.06	1.04	0.937	1.460
RESULTS						
Duration of Test	6hr. 30min.	6 hours	7 hours	7 hours	5Hr.50 Min.	6Hr. 30Min.
Total Coal Burned - lbs.	92	154	61.5	49.2	48.7	114.7
Coal Burned per hour - lbs.	14.1	25.7	8.8	7.0	8.35	17.6
Coal Burned per sq.ft.Grate/hr.	10.0	18.3	6.3	5.0	6.0	12.5
Weight of Air circulated lbs/hr.	2300	2490	2046	2010	1986	2652
Volume of Air at room Tem.cu.ft./min.	615	673	541	530	534	714
Weight of Air Circulated per lb. Coal burned	163	97	233	287	237	151
Heat Deliv. thru register BTU/hr.	71300	105000	47600	39600	45700	92600
Heat Release per cu.ft. of furnace Volume - BTU per hour	41900	76400	26200	21700	26000	54700

HEAT BALANCE	BTU	%	BTU	%	BTU	%	BTU	%	BTU	%	BTU	%
Heat Delv. thru register=efficiency	5050	40.8	4080	33.0	5410	43.7	5650	43.7	5470	42.4	5260	40.7
Heat Loss Due to Moisture in Coal	60	0.5	65	0.5	56	0.5	45	0.4	45	0.4	52	0.4
Heat Loss Due to Burning Hydrogen	676	5.5	730	5.9	628	5.1	625	4.9	643	5.0	728	5.6
Heat Loss in Dry Chimney Gases	2380	19.2	3860	31.2	2280	18.4	2510	19.4	2610	20.2	3570	27.6
Heat Loss Due to Burning to CO	368	3.0	366	2.9	275	2.2	00	0.0	190	1.4	285	2.2
Heat Loss Due to Soot in Smoke)			306	2.5	170	1.4	152	1.2	137	1.0	214	1.7
Radiation and Unaccounted for)	3850	31.0	2977	24.0	3567	28.8	3938	30.4	3825	29.6	2811	21.8
	12384	100.0	12384	100.0	12384	100.0	12920	100.0	12920	100.0	12920	100.0

DATA AND RESULTS OF TESTS

HOLLAND FURNACE-- STOKER FIRED.

Test Number	1A	3	4	5	5A
Date 1932	May 3rd	Aprl.11	Apr. 12	Apr. 13	May 4
Size of Coal	1"slack	1"slack	1"slack	1"slack	1"slack
Opening of Stoker Blower Damper	2 turns	2½ turns	2 turns	2 turns	2 turns
Speed of Stoker from pulley ratios	Slow	Slow	Slow	Slow	Slow
Setting of Room Thermostat	85 deg.	85 deg.	85 deg.	85 deg.	85 deg.
Setting of Furnace Thermostat	250	325	350	400	425
PROXIMATE ANALYSIS OF COAL as FIRED					
Volatile Matter - Percent	43.71	44.51			43.71
Fixed Carbon	39.21	39.92			39.21
Ash	7.92	7.76	Ditto	Ditto	7.92
Sulphur	.94	.94			.94
Moisture	8.23	6.87			8.23
Heating Value - B.T.U. per lb.	11950	12,150			11950
FLUE GAS ANALYSIS					
Carbon Dioxide - CO_2 %	5.9	9.1	11.1	13.5	13.4
Oxygen O_2	13.0	10.4	8.0	5.0	5.0
Carbon Monoxide-CO	0.0	0.0	0.1	0.2	.5
Pounds of Air per lb.Coal as fired	17.9	17.8	14.7	12.1	12.0
Percent Excess Air	160	98	60	30.0	32.5
FLUE GAS SAMPLE					
Cu. Ft. Drawn	126.7	95.5	94.9	67.9	106.3
Av. Suction Press In. Hg.	3.09	3.0	3.3	3.6	3.58
Aver. Temperature- Deg. C.	26.80	29.2	28.5	29.0	26.40
Weight of Carbon - Grams	.5548	.40	.83	0.812	.7478
Weight of Fly Ash - Grams	.369	.19	.226	0.136	.242
Lbs. Carbon in Chimney Gases/100#Coal	.32	.31	.545	.628	.35
Lbs. Fly Ash " " " " "	.24	.13	.148	.105	.11

STOKER FIRED TES

Test Number	1 A	3
PRESSURES		
Barometer - Inches Mercury	25.13	25.38
Draft of Smoke Collar-in.water	0.16	.07
Draft over Fire - " "	0.095	
Pressure in Pipe to Tuyers "	0.038	
Circulating Fan Pressure" "	0.35	.40
Differential Press, across Orifice	9.20	10.45
TEMPERATURES- Deg. F.		
Room	77.5	79.0
Air Inlet	77.5	79.0
Hot Air Outlet, Aver. 3 Risers	194.0	217.0
Temperature Rise-Inlet to Outlet	116.5	138.0
Flue Gas at Smoke Collar	680.0	795.0
C.I. Wall of Firepot	621.0	702.0
Gases in Circular Radiator	850.0	1002.0
Length of Time ea. Stoker Operation	8 min.	4.8
Length of Time bet. " "	25 "	11.6
Power - K.W. hours per ton of Coal		

TS cont'd

4	5	5A
25.34	25.36	25.14
.08	.08	0.15
.08	.06	.07
.52	.55	.51
.40	.46	.38
9.76	11.90	11.30
80.0	80.0	75.5
80.0	80.0	75.5
246.0	262.0	269.5
166.0	182.0	194.0
792.0	853.0	875.0
810.0	965.0	923.0
1042.0	1130.0	1150.0
6.0	5.6	11.0
13.4	9.7	15.0
		14.6

Test Number	1A	3
RESULTS		
Duration of Test	7 Hours	6 Hours
Total Coal Burned - lbs.	61.75	71.0
Coal Burned per hr. - lbs.	8.83	11.8
Weight of Air Circulated - lbs. per hr.	2034	2163
Volume of Air at Room Temp. Cu.ft./min	540	578
Weight of Air Circulated per lb. Coal Burned	230	183
Heat Delivered thru register-BTU/hr.	56800	71,600
Heat Release per cu.ft. of furnace Volume-BTU. per hour	26200	35,800

HEAT BALANCE	B.T.U.	%	B.T.U.	%
Heat Delivered thru register=Efficiency	6430	53.8	6070	50.0
Heat Loss Due to Moisture in Coal	107	0.9	94	0.8
Heat Loss Due to Burning Hydrogen	644	5.4	683	5.6
Heat Loss in Dry Chimney Gases	2660	22.3	3140	25.8
Heat Loss Due to Burning to CO	0	0.0	0	0.0
Heat Loss Due to Carbon in Smoke	48	0.4	46	0.4
Radiation and Unaccounted for	2061	17.2	2117	17.4
TOTAL HEAT, Per Pound of Coal	11950	100.0	12150	100.0

4	5	5A
6Hr.20min.	6 Hrs.	7 Hrs.
87.5	93	138
13.8	15.5	19.7
2082	2304	2260
561	618	594
151	149	114
83000	100700	105500
41800	47000	58500

B.T.U.	%	B.T.U.	%	B.T.U.	%
6020	49.6	6500	53.5	5350	44.8
94	0.8	96	0.8	117	1.0
681	5.6	695	5.7	695	5.8
2590	21.3	2340	19.3	2390	20.0
60	0.5	99	0.8	240	2.0
79	0.7	91	0.7	51	0.4
2626	21.5	2329	19.2	3107	26.0
12150	100.0	12150	100.0	11950	100.0

A sample of the slack coal used on the stoker tests was screened to determine the relative proportion of coarse and fines. The screen analysis was as follows:

Passed Through Screen No.	Passed Through Size of Opening Inches	Retained on Screen No.	Retained on Size of Opening Inches	Percent of Sample retained on Screen	Accumulative Percent retained on Screen
			1.050	0.96	0.96
	1.050		0.742	2.19	3.15
	0.742		0.525	10.72	13.87
	0.525		0.371	15.65	29.52
	0.371	3	0.263	13.00	42.52
3	0.263	4	0.185	10.95	53.47
4	0.185	6	0.131	9.27	62.74
6	0.131	8	0.093	6.85	69.49
8	0.093	10	0.065	5.67	75.26
10	0.065	14	0.046	5.23	80.49
14	0.046	20	0.0328	4.04	84.53
20	0.0328	28	0.0232	3.25	87.78
28	0.0232	35	0.0164	2.86	90.64
35	0.0164	48	0.0116	2.13	92.77
48	0.0116	65	0.0082	0.45	93.22
65	0.0082	Pan		6.78	100.00
				100.00	100.00

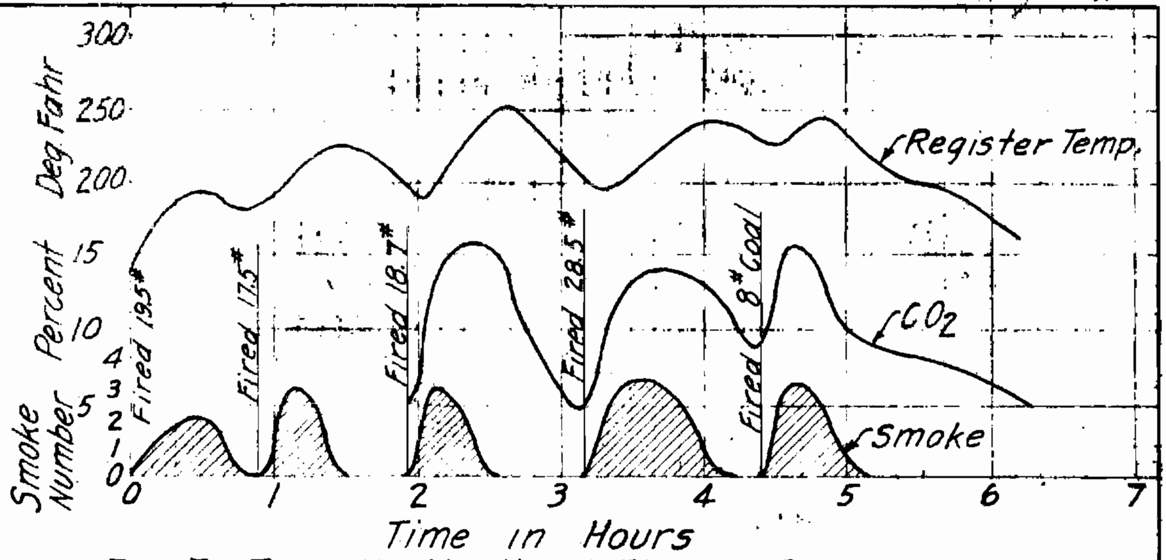


Fig. 5. Test No. 41 Hand Fired, Pea Coal

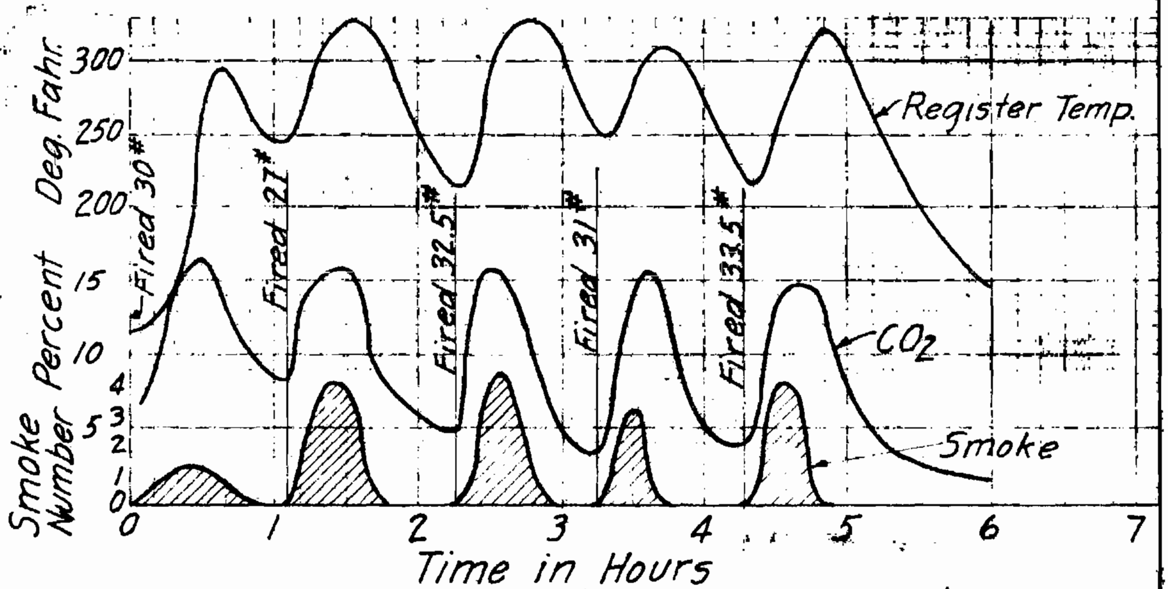


Fig 6. Test No. 42 Hand Fired, Pea Coal

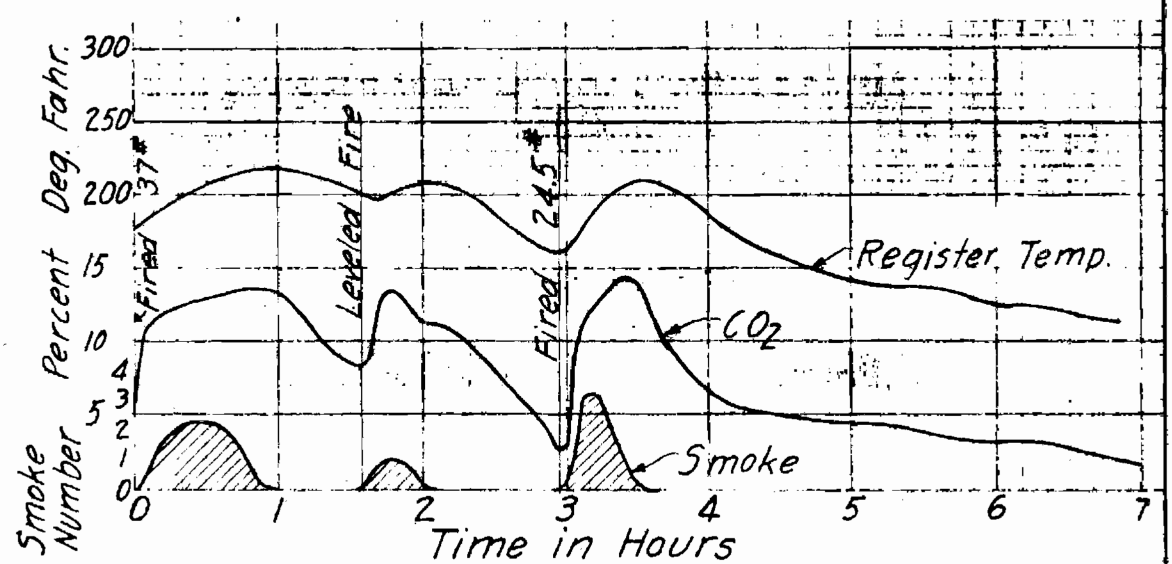


Fig. 7 Test No. 43 Hand Fired, Pea Coal

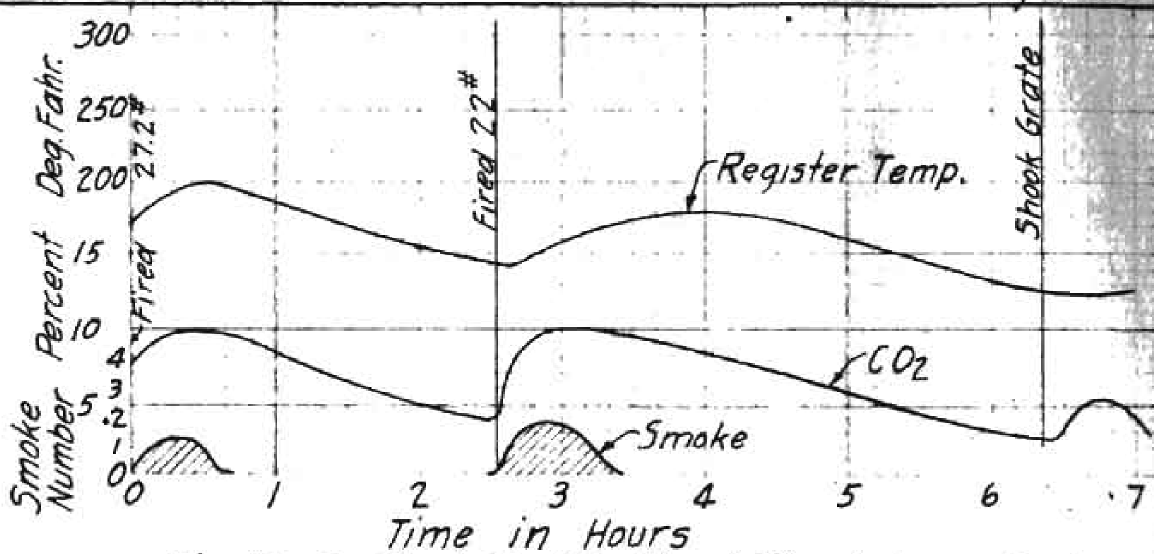


Fig. No. 8. Test No. 44 Hand Fired, Lump Coal

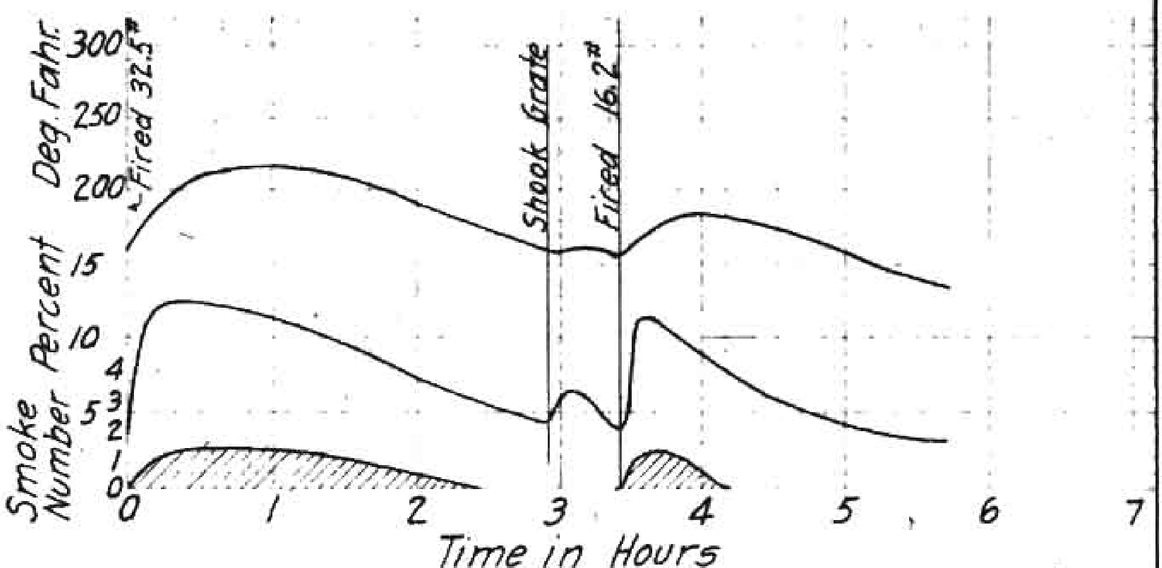


Fig. 9. Test No. 45 Hand Fired, Lump Coal

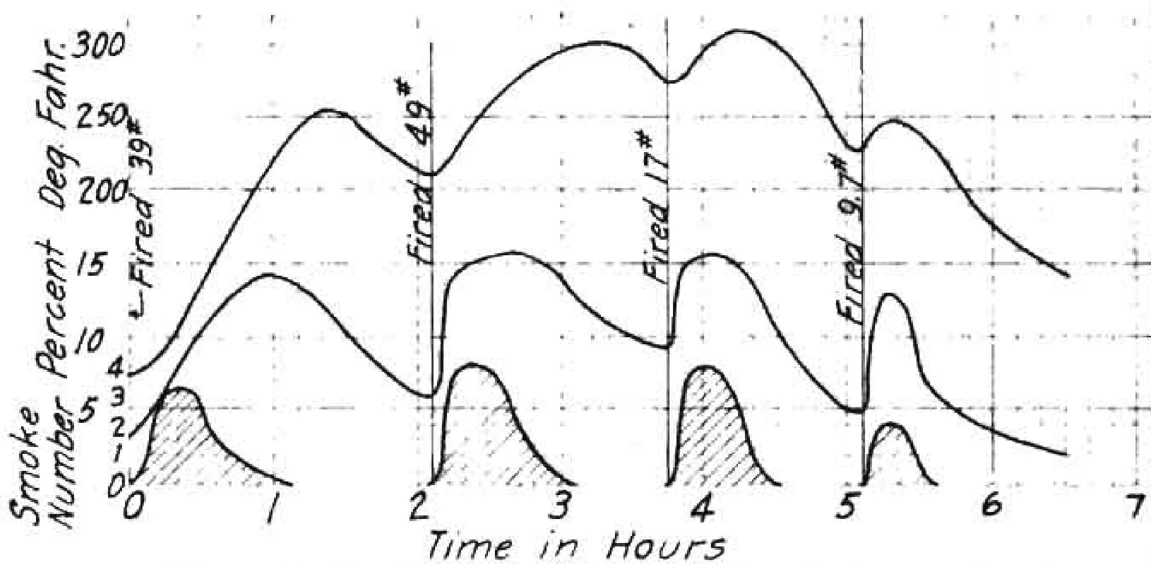


Fig. 10. Test No. 46 Hand Fired, Lump Coal

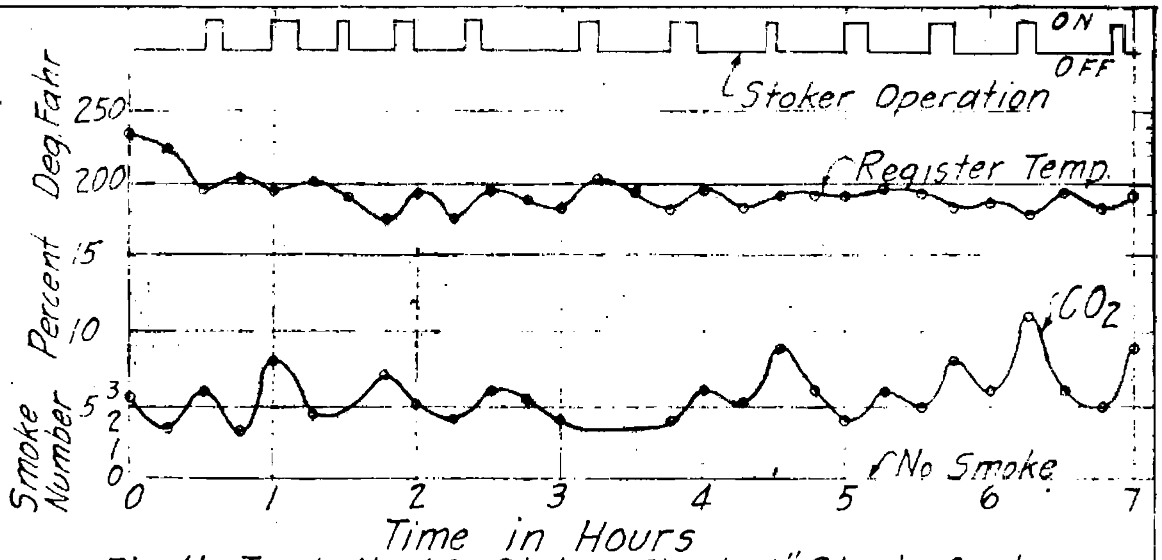


Fig. 11 Test No 1A Stoker Fired, 1" Slack Coal

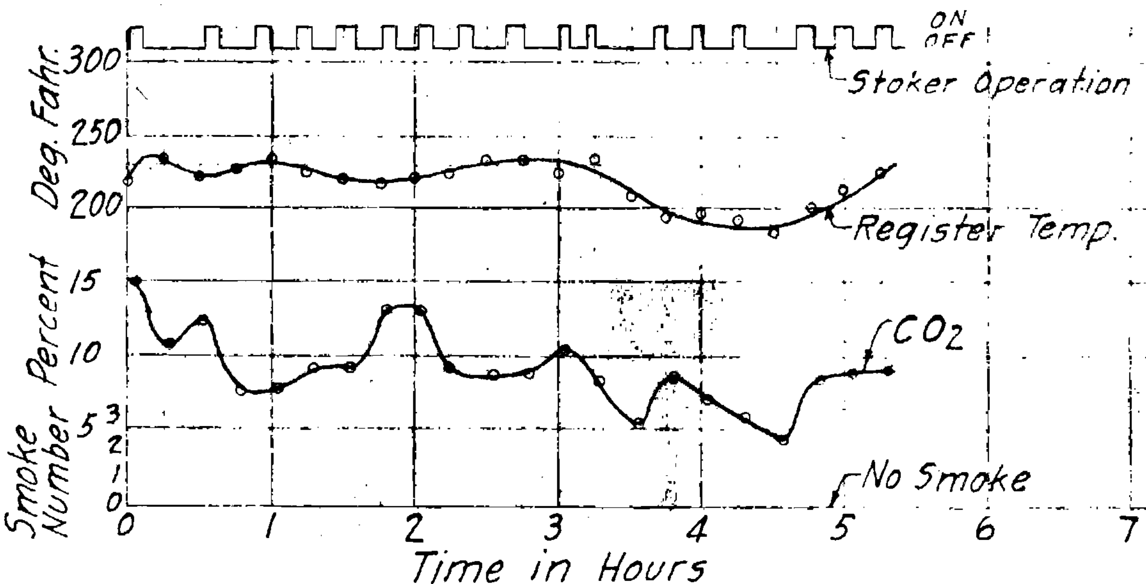


Fig. 12. Test No. 3 Stoker Fired, 1" Slack Coal

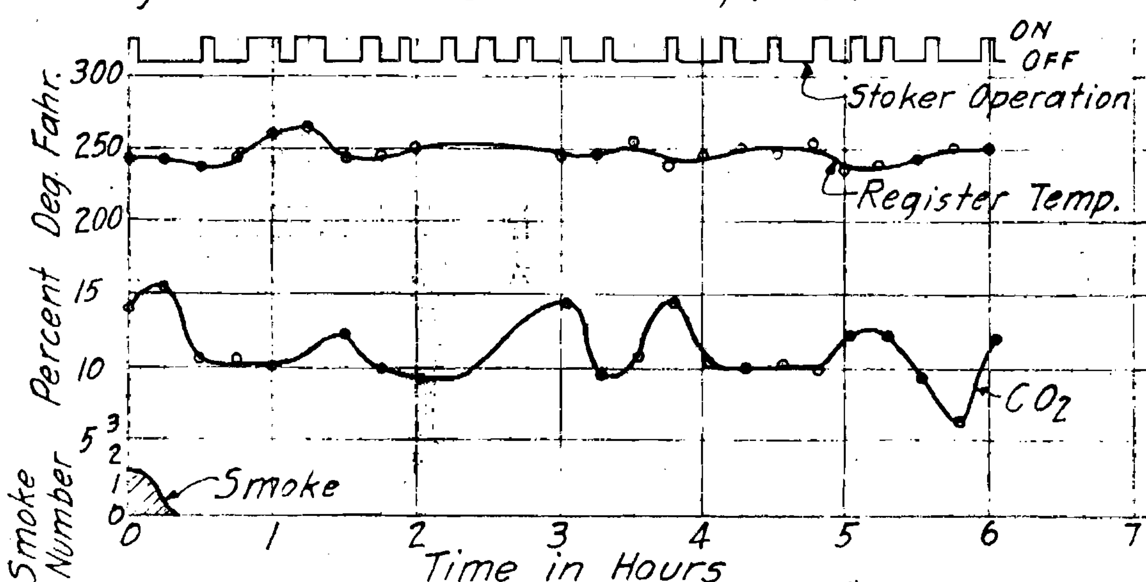


Fig. 13 Test No. 4 Stoker Fired, 1" Slack Coal

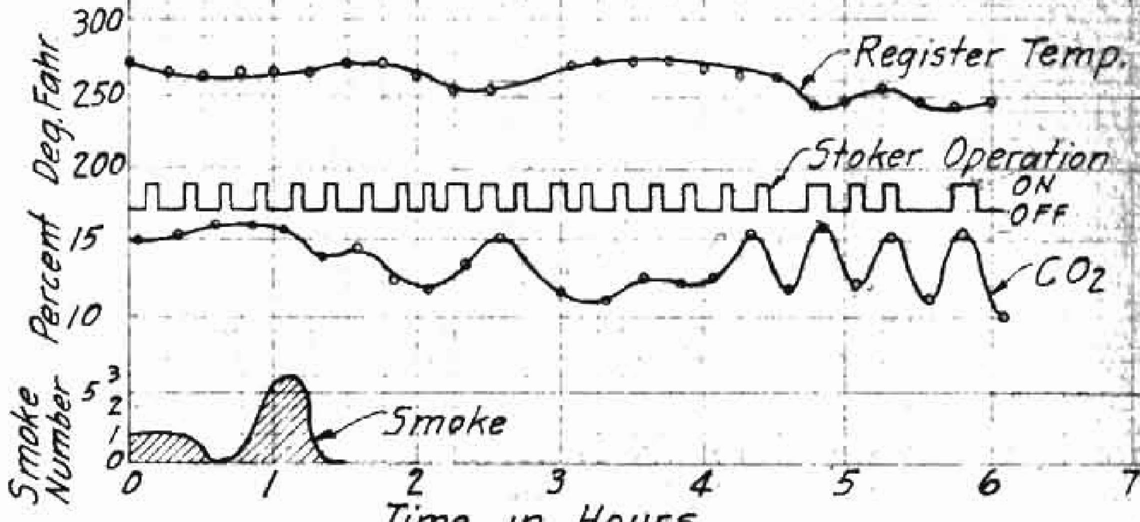


Fig. 14 Test No. 5 Stoker Fired, 1" Slack Coal

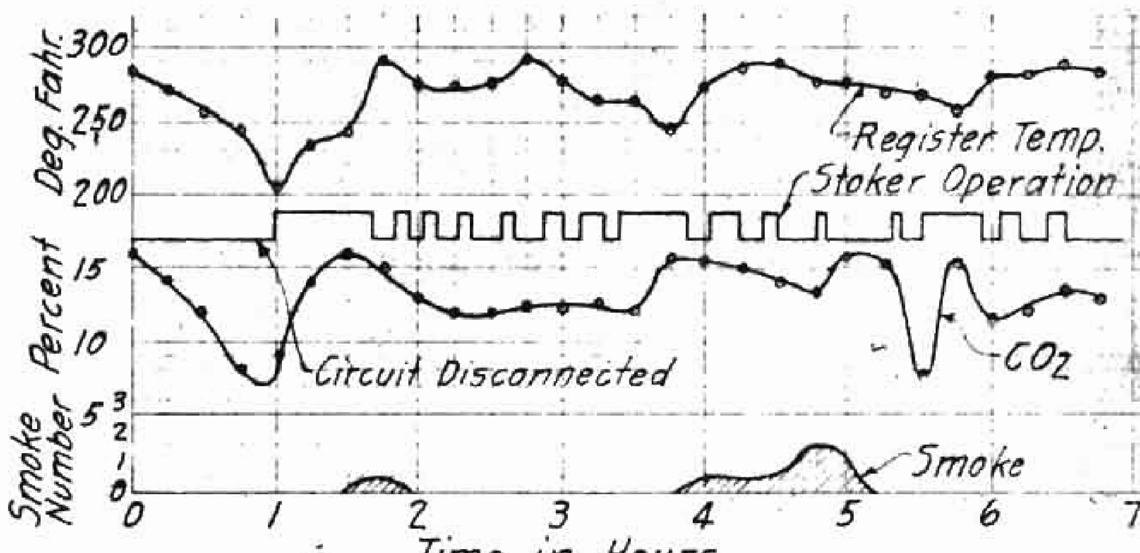


Fig. 15. Test No. 5A Stoker Fired, 1" Slack Coal

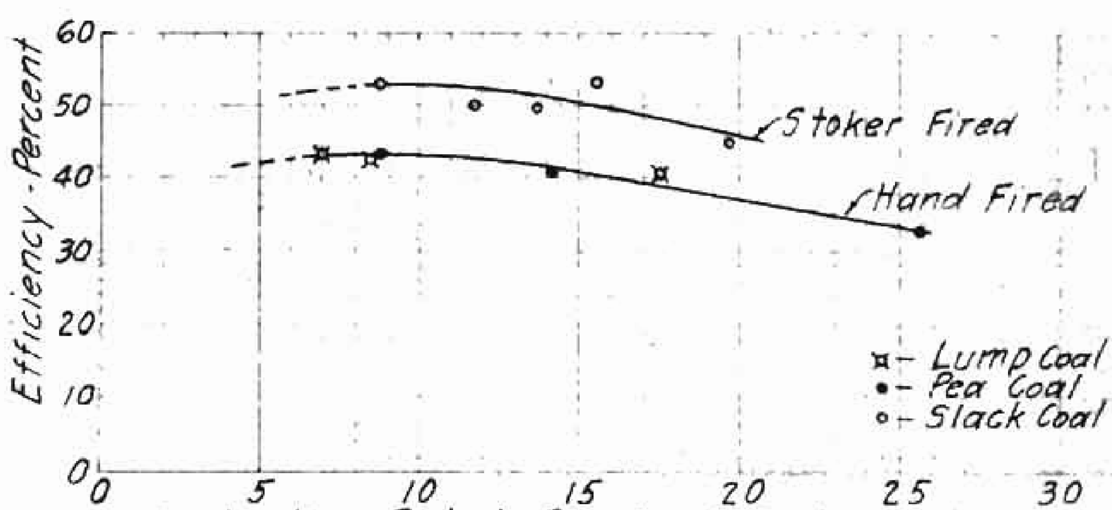


Fig. 16. Efficiency Curves for Hot Air Furnace

10. SAMPLE COMBUTATIONS

The complete computations will be given for Stoker Test No. 5 showing the method of arriving at the results.

The weight of air circulated through the furnace casing is found by using the formula for the fan and orifice as developed on Page 17. The weight of air per minute equals $Q'' = 51.34\sqrt{\frac{h\,P}{T}}$

Where, h = manometer reading = 11.90

P = absolute pressure of air in inches of mercury = Barometer reading plus static head of fan = 25.36 + .46/13.6 = 25.39"

T = absolute temperature of air equals 460 deg. plus temperature of air in degrees Fahr. = 460 + 80 = 540 deg. Asb.

Then $Q'' = 51.34\sqrt{\frac{11.9 \times 25.39}{540}} = 38.4$ lbs. per minute, or 2304 lbs. per hour.

The density of the air = 1.322 P/T = 1.322 x 25.39/540 = .0622 lbs. per cu. ft.

Then the volume of free air, i.e., at room temperature and pressure = weight, divided by the density = 38.4/.0622 = 618 cu. ft. per minute.

The weight of air circulated per pound of coal burned = 2304/15.5 = 149 pounds; 15.5 being the weight of coal burned per hour.

The heat taken up by this amount of air in passing through the furnace casing equals the weight of air times the temperature rise times the specific heat of air = 2304 x 182 x .24 = 100,700 B.T.U. per hour. The heat per lb. of coal = 149 x 182 x .24 = 6500 B.T.U. This is the useful heat delivered through the hot air register and is the value upon which the efficiency is based. The furnace efficiency = 6500 divided by the heat value per pound of coal = 6500/12,150 = 53.5 per cent.

The heat losses from the furnace consist of the losses up the stack plus the radiation to the air surrounding the furnace. Part of the stack losses consist of water vapor superheated to the temperature of the exit gases. This loss per unit weight of vapor equals the heat required to heat a pound of water from room temperature to the boiling point, evaporate the water into steam and then superheat the steam to the exit gas temperature. For this test the room temperature equals 80 deg. the boiling point of water = 204 deg. and the exit gas temperature equals 855 deg. Then the heat loss = (204 - 80) + 970 + .47 (855 - 204) = 1400 B.T.U. per lb. of water vapor. The heat loss due to moisture in the coal = 1400 times the weight of moisture per lb. of coal = 1400 x .0687 = 96 B.T.U.

The hydrogen in the coal burns to H_2O and passes out as water vapor. The amount of vapor formed = 9 times the percent hydrogen in the fuel divided by 100 = 9x .0592 = .533 pounds per pound of dry coal. Since the heat balance is based on a pound of coal as fired this must be multiplied by the weight of dry coal per lb. of coal as fired, or, .533 x (1.0000 - .0687) = 0.496 lbs. The heat loss due to the Hydrogen in the fuel then equals .496x1400 = 695 B.T.U. The reason this is considered a loss is that the heat value of a pound of coal is determined in a calorimeter in which the products of combustion are cooled down to room temperature, thus condensing the water vapor formed.

The heat loss in the dry chimney gases per lb. of coal equals the weight of gases times the specific heat times the temperature rise of the gases above that of the room. The weight of gases passing up the chimney per lb. of coal is calculated from the flue gas analysis and ultimate analysis of the coal. To facilitate the work of the tests the two charts Figures 17 and 18, were plotted from calculated data, using the ultimate analysis of a representative Utah Coal. An ultimate analysis of the coal actually used on the tests was not made, but the analysis of coal from the same mine, as reported by the Bureau of Mines, shows very little difference from the analysis used. The Orsat analysis of the flue gas always checked very closely with the relations as given on Fig. 17.

The weight of dry flue gas per pound of dry coal is found from Fig. 18 corresponding to a CO_2 value of 13.5 per cent to be 13.5 lbs. The weight per lb. of coal as fired is then 13.5 x .9313 = 12.58 lbs. The temperature rise of the flue gases is 855 - 80 = 775 deg. The heat loss is then, 12.58 x .24 x 775 = 2340 B.T.U.

The heat loss due to incomplete combustion of carbon to CO instead of CO_2 is given by the formula

$$\frac{CO}{CO_2 + CO} \times C \times 10160$$

Where CO and CO_2 are the percentages found in the flue gas analysis, C the weight of carbon per lb. of coal and the constant 10160 represents the number of heat units generated in burning one pound of carbon in carbon monoxide to carbon dioxide. For our test this gives

$$\frac{.2}{13.5 + .2} \times .7186 \times 10160 = 106.5 \text{ B.T.U.}$$

The percent of carbon is based on the analysis of dry coal, so to refer to coal as fired we multiply 106.5 x .9313 = 99.2 B.T.U.

The volume of sample of flue gas drawn through the soot collecting filter was 67.9 cu. ft. at 29 deg. Cent. and a suction pressure of 3.6 inches of mercury. The weight per cu. ft. of gas at these conditions 0.735 x P/T = 0.735 x 21.76/(273 + 29) = .0527 lbs. per cu. ft. The weight of the sample drawm is then .0527 x 67.9 = 3.58 lbs.

During the time this sample was being drawn, a weight of flue gases passed up the stack equal to the weight of coal burned times the weight of gases per lb., of coal as given above = 93 x 13.5 x .9313 = 1170 lbs.

The weight of carbon collected in the filter was .812 grams, and .812 x .0022 = .00179 lbs. The total carbon in the flue gases was 1170 x .00179/3.58 = .585 lbs.

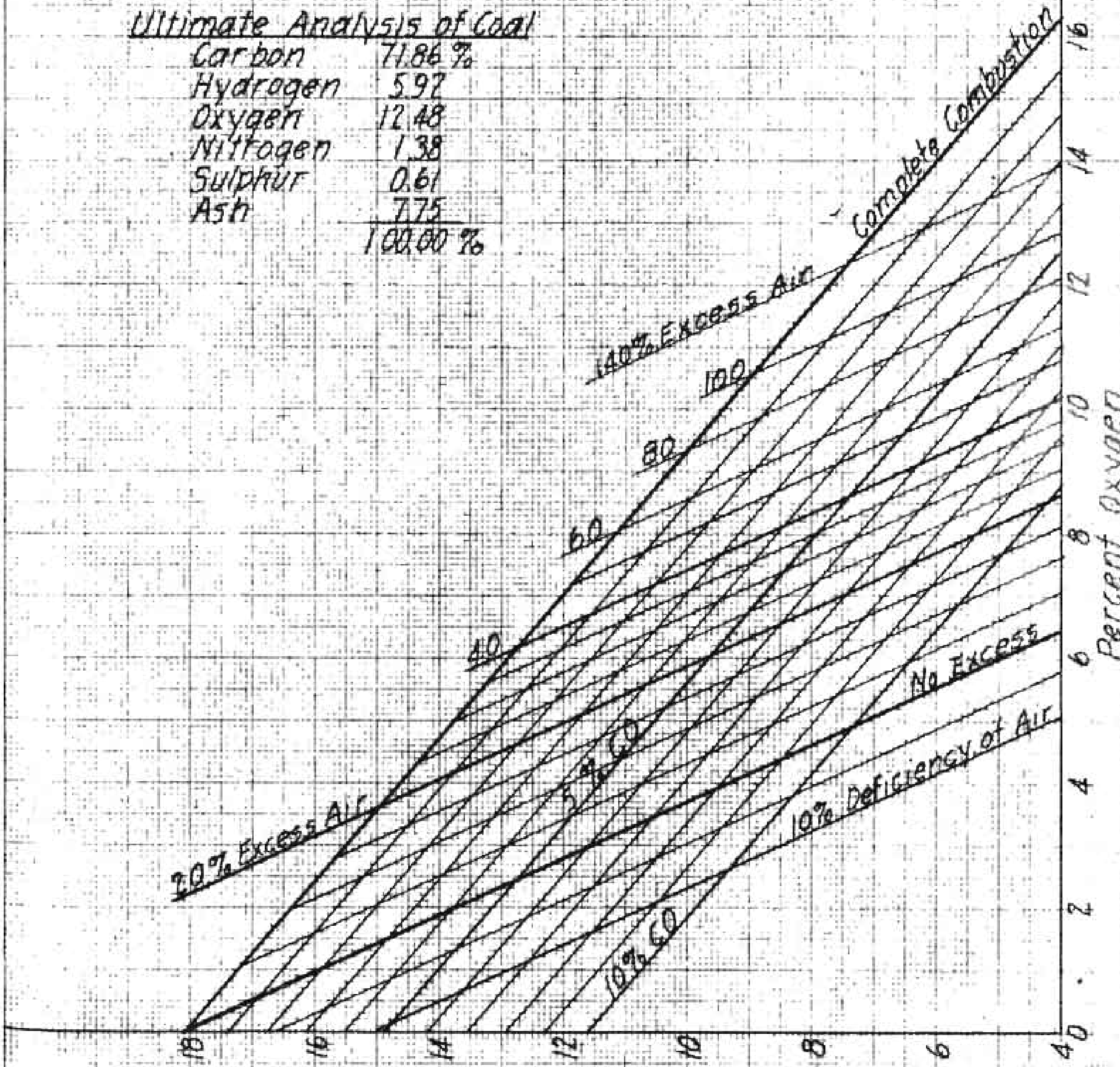
The weight of carbon in the flue gases per lb. coal burned = .585/93 = .00628 lbs. The heat loss due to this unburned carbon is .00628 x 14,600 = 91.6 B.T.U. per pound of coal as fired.

Similarly the weight of fly ash in the sample = .136 grams = .000299 lbs. Total fly ash in flue gas = 1170 x .000299/3.58 = .098 pounds, and the fly ash per lb. of coal burned = .098/93 = .00105 lbs.

The heat loss due to radiation and unaccounted for is taken as the remainder which when added to the above items in the heat balance gives the total heat per pound of coal burned. Its value on test No. 5 is 2329 B.T.U. or 19.2 percent.

Figure 17

Chart For Use In
Flue Gas Analysis
Of Utah Coal



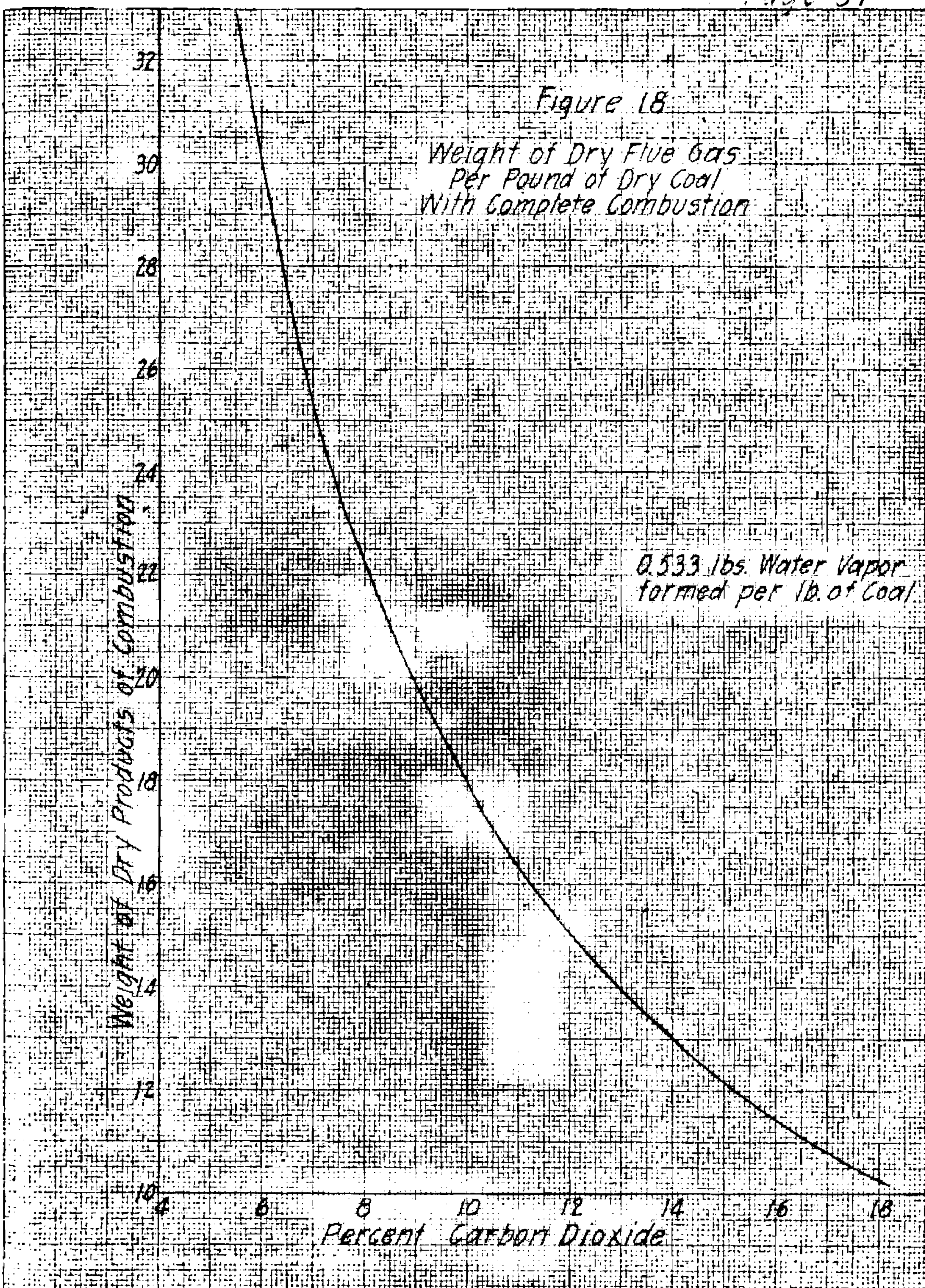


Figure 18
Weight of Dry Flue Gas
Per Pound of Dry Coal
With Complete Combustion
0.533 lbs. Water Vapor
formed per lb. of Coal
Weight of Dry Products of Combustion
32
30
28
26
24
22
20
18
16
14
12
10
4
6
8
10
12
14
16
18
Percent Carbon Dioxide

11. Discussion of Results.

The efficiency of the furnace as found on the various tests is shown graphically on Fig. 16. We note first that the efficiency on the stoker tests is nine or ten percent higher than for hand firing. The actual weight of coal per 1000 B.T.U. delivered through the register is 16.2 percent less for stoker firing than for hand firing. The efficiency on the hand fired tests is but slightly lower than those reported by the University of Illinois, Bulletin 120, 141, and 188 when using bituminous coal. The efficiency of a hot air furnace is naturally lower than for steam boiler furnaces since the flue gases leave at a much higher temperature and the radiation loss is a greater percent of the heat input.

The efficiencies of the hand fired tests all lie on a smooth curve, see Fig. 16, which show the tests to be very accurate. The reason the stoker fired tests are not so consistant is that it was much harder to end the test with the same size fire as at the start. The hand fired tests were started and ended with a low fire, hence it was easier to estimate the amount of fuel on the grate. The stoker fired tests were run with a deeper fuel bed to allow a constant firing rate. The coal had a tendency to coke and hold up in cones for a while, then drop down making it very difficult to judge the actual amount of fuel in the furnace. Even with this small error, the stoker fired tests at all rates showed a gain over hand firing.

We also note from Figs. 5 to 15 the big reduction in smoke emission for the stoker fired tests compared with the hand fired. With hand firing, the furnace emitted smoke from 20 minutes to one hour following each charge of coal while the stoker firing produced no smoke except for short periods when the fire was crowded.

The gain in efficiency and elimination of smoke can both be accounted for on the theory of combustion of the underfeed stoker. Here we have the green coal fed from underneath the burning bed of coals and the volatile matter is distilled comparatively gradual and must pass up thru the hot bed of coals where it is mixed with air and both heated to an intense heat. This mixing and heating insures good combustion. The heavy hydrocarbons are cracked on passing through the hot coals and the temperature is high enough to ionize the resulting free carbon and it reacts with oxygen liberating heat.

With hand firing a big charge of coal is admitted to the hot fire pot and the tendency is for the volatile matter to be driven off rather quickly. There is not sufficient time nor mixing to allow all these volatiles to enter into reactions with oxygen, hence much free carbon from the cracking process escapes as well as some hydrocarbons. Comparing the radiation and unaccounted-for loss on the two methods of firing, we see the value on the stoker tests is about 10 percent higher than for the hand fired tests. The efficiency is about this much higher for the stoker tests. It is reasonable to expect the radiation loss to be about the same for the two methods, leaving us quite sure that about ten percent of the heating value of the fuel escaped up the stack as volatile combustible matter in addition to the carbon monoxide and solid carbon found in the flue gas sample.

The temperature of the air passing through the register was also much more constant for the stoker fired than for the hand fired tests. This can be attributed to the thermostatic control of the stoker operation. The curves representing register temperature are but rough averages of the actual conditions since they are plotted from readings taken at 15 minute intervals. Several series of readings were taken at one minute intervals to determine the actual rise and fall of temperature in co-ordination with the stoker operation. A typical example is as follows: The temperature reached a minimum of 275 deg. just as the stoker started to fire. The stoker ran for five minutes. The temperature rose to 286 deg. at the end of the five minutes and continued to rise, reaching a maximum of 289 deg. two minutes later. The temperature then fell gradually to 272 deg. The stoker again started up after being off 16 minutes. We see, then, that the temperature varied about 15 degrees on each cycle of stoker operation. We call attention again to the fact that the stoker was being controlled by the safety limit switch in the furnace bonnet and not by the room thermostat. The room thermostat works on a narrower range of temperature than this.

It is hoped that the Coal Research Dept. can be financed so that more extensive stoker tests can be run as outlined on page 7. The results of the few tests reported here show the possibility of the underfeed stoker in increasing the efficiency of the heating plant along with almost complete elimination of smoke. The stoker also offers the comforts of thermostatically controlled heat, keeping the house at an even temperature and still flexible to permit raising or lowering the temperature to suit conditions. The stoker provides the convenience of automatic firing, requiring only a few minutes attention once or twice a day.

All these desirable results are obtained by burning slack coal, which is the cheapest size on the market. No other fuel on the local market supplies nearly the heating value per unit cost than does Utah slack coal. Therefore, from the standpoint of greatest economy to the individual and greatest service to our state, we recommend the use of UTAH COAL, OUR GREATEST NATURAL RESOURCE.

III. TESTS OF THE PORTER FURNACE.

1. Object of Tests.

The object of the tests on this furnace was to study the combustion characteristics of this new device and find to what extent it would eliminate smoke. It was also studied from the standpoint of durability, cost of repairs and ease of operation.

2. General Description of Furnace.

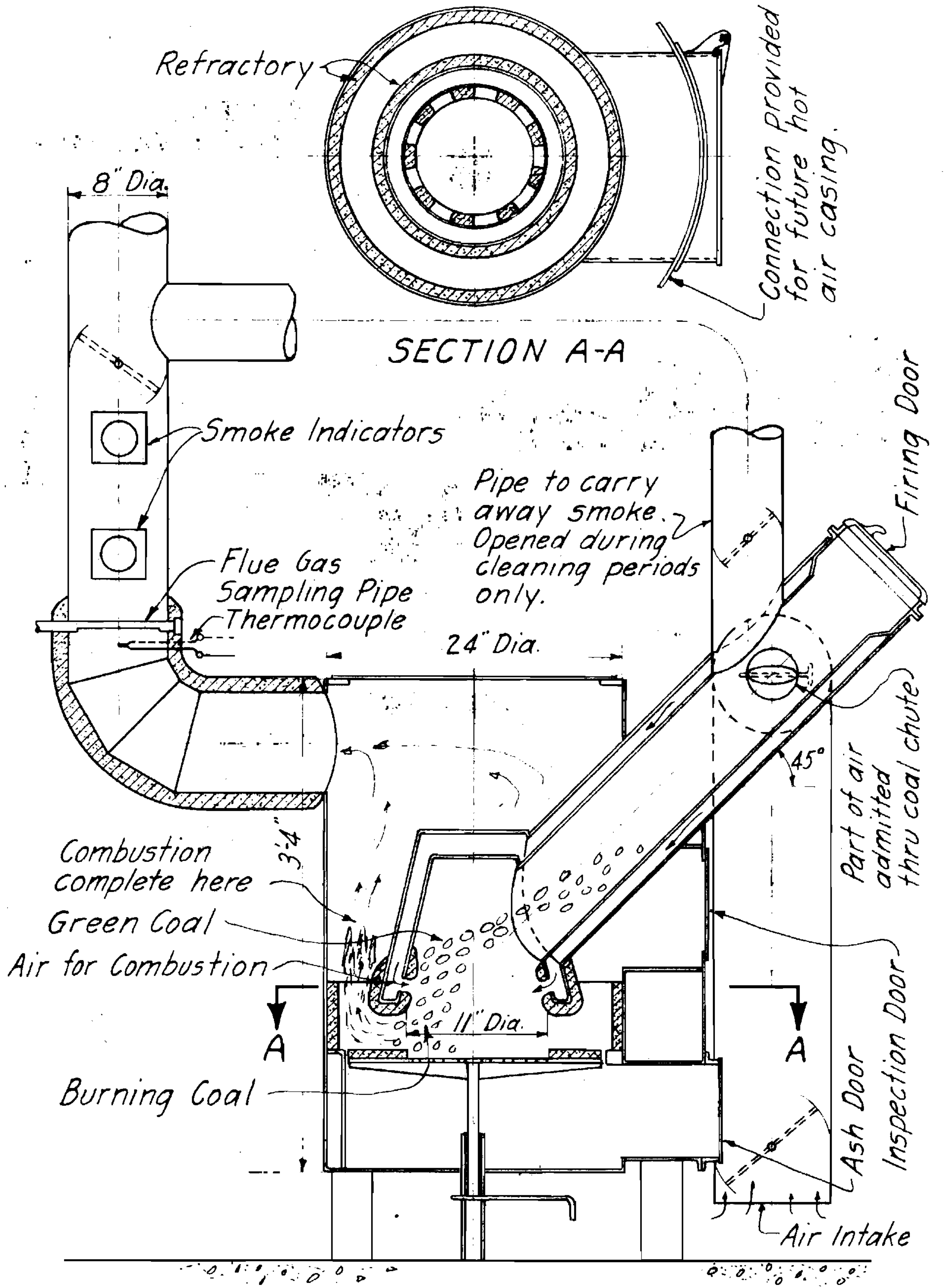
This furnace was designed and built by Mr. Zenos Porter of Provo, Utah and installed by Mr. Porter free of charge to the University of Utah. The arrangement of the furnace is shown in Fig. 19.

Coal is admitted through the sloping magazine where it feeds by gravity on to the grate. Air for combustion comes down through the annular space surrounding the coal chute, and is preheated before passing through the tuyere openings into the bed of coals. The coal in the lower portion of the cone burns and the products of combustion have to pass down around the bottom of the refractory covered tuyere cone and up through an annular ring lined with refactory. The volatile products are distilled out of the green coal covering the live coals and have to pass down through the hot bed, where they mix with air coming through the tuyeres. Here we have a splendid combination of the physical conditions which give good combustion, namely, (1) gradual distillation of the volatile products, (2) passing the volatiles through a zone of intense heat, (3) turbulent flow of gases to insure good mixing, and (4) passing the burning gases over hot refractory surfaces which have a catalytic action in accelerating combustion.

The furnace was provided with connections for a hot air casing, but it was not installed. Leaving off the casing made it much easier to observe the operation and easier to open up for inspection and changes. The casing will be installed and actual efficiency runs made after the preliminary study is completed and necessary changes made.

3. Method of Observing Data.

The temperatures were measured by means of thermocouples and the same central switchboard as shown in Fig 2. Page 12.



GENERAL ARRANGEMENT OF PORTER FURNACE
Figure 19

Scale 1" = 1'-0"

The smoke observations and flue gas analysis were made with apparatus similar to that used on the Holland furnace and shown in Fig. 4, Page 19. The soot filter was made of a crucible with porous bottom and filled with asbestos wool. This type of filter did not always give consistent results so the alundum thimbles were purchased and used on the later tests.

4. Operation of the Furnace.

The tests were begun by starting the fire with paper and kindling, plus 15 to 18 lbs. of pea coal. At ten minute intervals the temperatures were read and the flue gas analyzed. The smoke pipe was constantly watched and records made of the density of the smoke and duration of smoking. Coal was added at frequent intervals, the object being to keep a supply of green coal over the burning coals most of the time. The magazine was not quite steep enough for the coal to slide down freely so the firing was done in smaller quantities than would have otherwise been done. With the loosely fitting dampers, the air could not be shut off tight enough to hold a fire overnight which necessitated starting up from a cold furnace each morning.

5. Data and Results of Tests
Porter Furnace.

Test Number	2	3	5
Date of Test - 1932.	Feb. 10	Feb. 11	Feb. 18
Duration of Test	3Hr.30min.	7 hours	6 Hr.30min.
Total Coal burned- lbs.	61.0	112.4	145.4
Coal burned per hr. lbs.	17.4	16.1	22.4
Average CO_2	7.0	6.0	8.7
Average stack draft inches water	.15	.15	.11
TEMPERATURES: Deg. F.			
Flue Gas-Average	978	948	1135
" " Maximum	1360	1217	1440
" " Minimum	60	60	60
Inner Lining, Aver	1470	1620	
" " Max.	1905	1925	
" " Min.	60	60	
Outer Lining, Av.	1135	1096	1126
" " Max.	1470	1520	1530
" " Min.	60	60	60
Top Steel Plate, Average	615	591	735
" " " Max.	835	910	1060
" " " Min.	60	60	60
Steel Shell, Aver.	840	802	970
" " Max.	1092	1096	1400
" " Min.	60	60	60

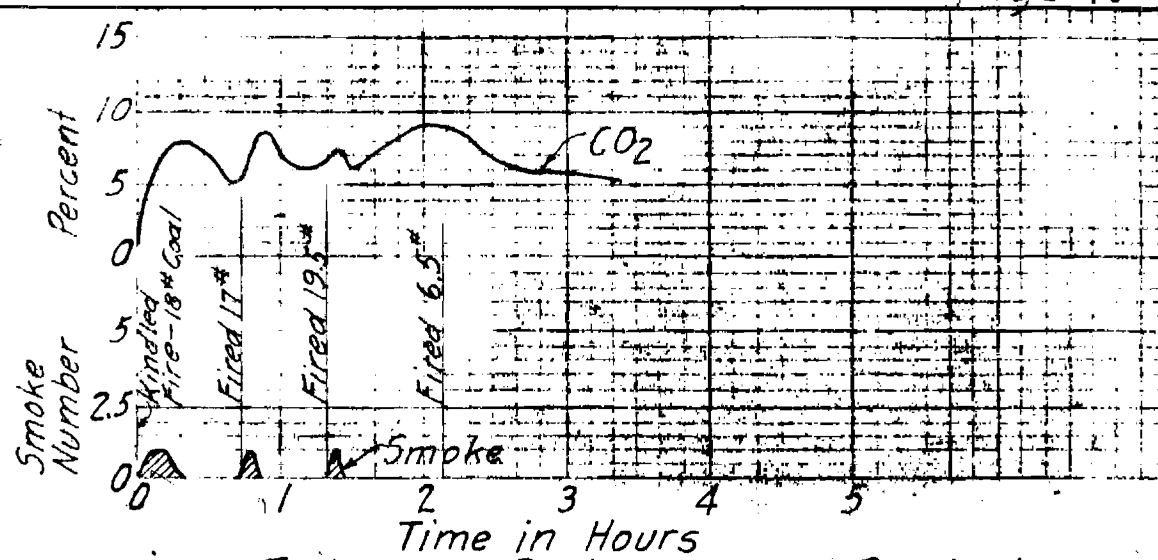


Fig. 20 Test No. 2 Porter Furnace, Pea Coal

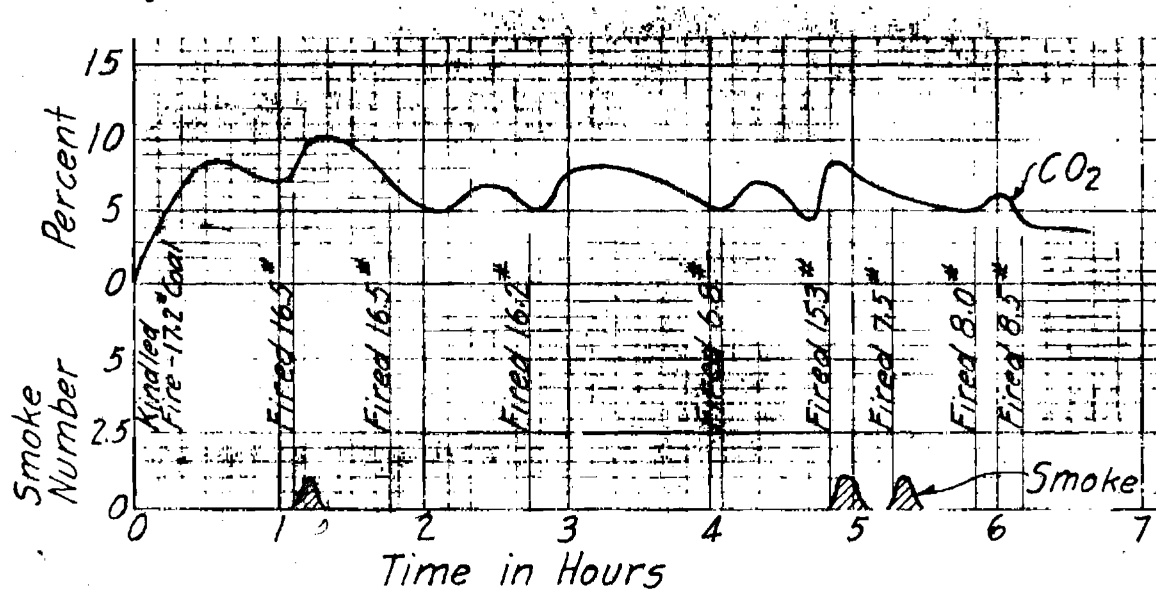


Fig. 21 Test No. 3 Porter Furnace, Pea Coal

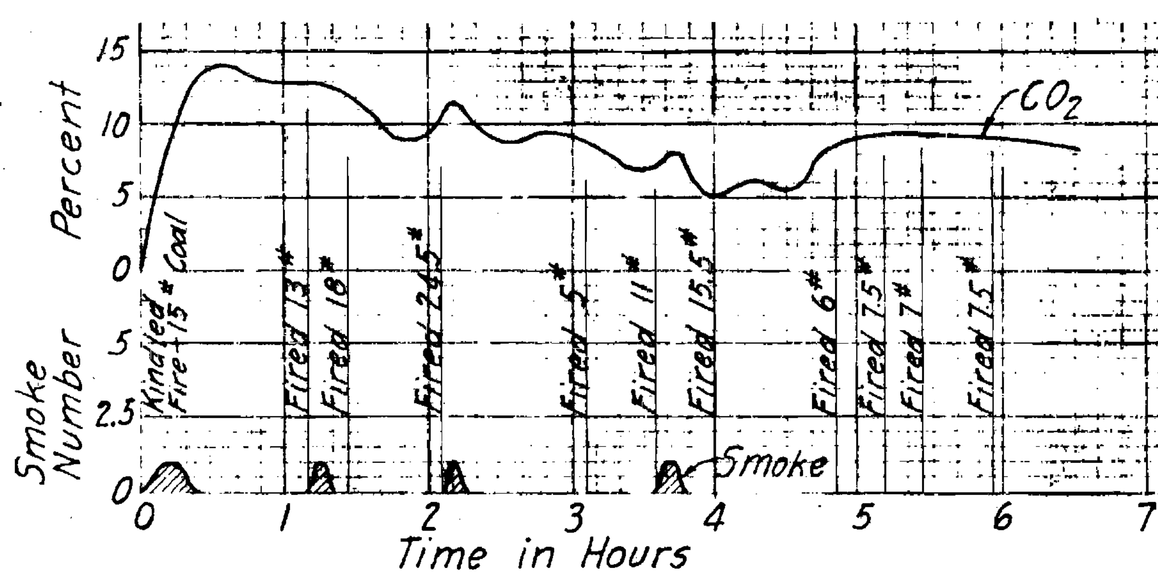


Fig. 22 Test No. 5 Porter Furnace, Pea Coal

6. Discussion of Results.

It will be noted from the graphs, Fgs. 30,31, and 32 that the smoke produced was negligible compared with the ordinary hot air furnace, hand fired-, see Fig. 6 Page 29. This bears out our theory of combustion and adds proof to our contention that the smoke nuisance we have in our cities today is not the fault of our coal but the fault of the equipment in which we burn it.

The percent carbon dioxide in the flue gas is rather low but can be attributed partly to leaks around the outer edge of the grate and center cone, allowing air to enter which did not pass through the fuel bed. Test No. 5 was run after certain repairs had been made on the center cone and we note that the CO_2 was higher than previously.

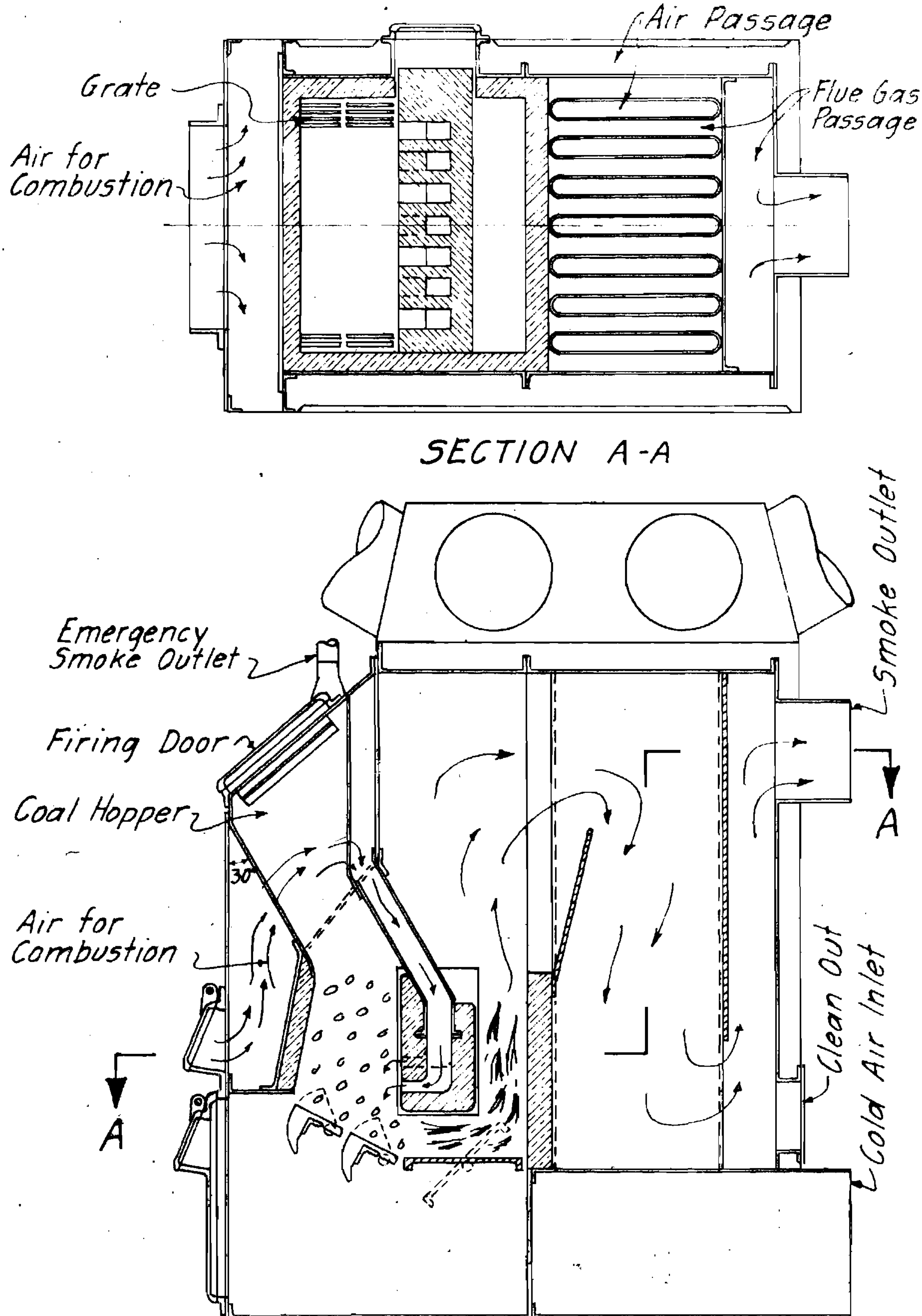
It will be noted that the flue gas temperature is exceptionally high and indicates that more heat conducting surface should be added. The temperatures of the refractory linings were not very high compared to the temperature of refactories in steam boiler furnaces. The outer lining showed no sign of fusing or otherwise deteriorating, but there was a slight glazing of the surface on the inner cone. More extended tests should be run to determine the comparative life of various refactory materials as well as the best methods of securing them to the steel.

The tests, therefore, show that this principle of combustion is very good and that with a reasonable amount of research and development a furnace could be put on the market which should be a big success and an asset to the coal industry.

7. Description of Proposed Porter Furnace.

After demonstrating the success of the principle of combustion used in the original furnace and noting certain defects which should be overcome, a design was made of a new furnace. The arrangement of the proposed furnace is shown in Fig. 33. Complete working drawings were made of this furnace and one would have been built had not the state held back in matching the $1500.00 contributed by the Coal Producers Association and spent previously by the Coal Research Dept.

It will be noted that the physical principles of the original furnace are embodied in the new design with certain changes in the arrangement and operating mechanism to make a more desirable furnace both from the



ARRANGEMENT OF PROPOSED PORTER FURNACE
Figure 23

Scale 1"=1'-0"

standpoint of operation and of heat transfer. The coal hopper is made large enough to hold a 24 hour supply for an ordinary residence, and the slope is made steep enough to insure a positive feeding down into the combustion zone. The refractory containing the openings for entrance of the air for combustion is suspended from a steel hanger in the same manner as suspended arches in large furnaces. This refractory block, which is the only one likely to burn out, can be quickly pulled out the side door of the furnace and replaced with a new one.

In this type of furnace only a small portion of the radiant heat of the fuel bed strikes the heat conducting surfaces, and the heat liberated by the fuel must be transferred from the hot flue gases by convection. The heating element in the proposed furnace is, therefore, designed to give an intimate contact between the flue gases and the heat transfer surfaces, with a liberal area of thin metal separating the gases and air.

The door for admitting the air for combustion is arranged so that it can easily be controlled with a thermostatic element, thus giving automatic control of the rate of combustion. With this element of automatic control together with the large supply of coal which would feed by gravity, a furnace of this type should be very desirable. Such a furnace would provide the ease of automatic firing, the comforts of thermostatic control, increased economy and also eliminate smoke.

The public should vigorously support a campaign to spread the use of such devices which will eliminate the smoke cloud from our skies, giving us cleaner air to breathe, cleaner clothes to wear, and cleaner homes in which to live.

IV. TESTS ON THE MCVAY COMBUSTION CHAMBER.

The following is a copy of the report of the tests at the McDonald Chocolate Company. Ninety copies of this report were made and distributed by the Utah Engineering Experiment Station and the Utah Coal Producers Association. A short summary of this report was published in the Bulletin of the National Coal Association and also of the Committee of Ten, Coal and Heating Industries, Chicago, Illinois.

F U E L   S T U D I E S

UTAH ENGINEERING EXPERIMENT STATION
IN CO-OPERATION WITH
UTAH COAL PRODUCERS ASSOCIATION.

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COMPARATIVE TESTS ON STEAM BOILER AT PLANT OF THE McDONALD CHOCOLATE COMPANY SALT LAKE CITY, UTAH. BEFORE AND AFTER INSTALLING THE McVAY COMBUSTION CHAMBER.

- - - - - - - - - -

By
OTTO DUKE,
RESEARCH FELLOW,
UNIVERSITY OF UTAH.

SEPTEMBER 23, 1931.

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RESULTS OF TESTS

	Old. Comb. Chamber 8 Hr. Test August 4.	New Comb. Chamber 8 Hr. Test August 12.	First 5 Hrs. of 8 Hr. Test August 20	First 8 Hrs. of 24 hour test Sept. 2.	24 Hour Test September 2.
PRESSURES					
Steam Pressure - lbs. per sq. in. gage	75.7	72.3	71.3	68.6	69.5
Barometer - Inches Mercury	25.35	25.38	25.41	25.43	25.43
Stack Draft - Inches Oil	.31	.33	.33	.39	.38
Draft Over Fire - Inches Oil	.25	.22	.22	.22	.22
Calorimeter Press - Inches Water	2.72	1.89	2.12	1.66	1.81
TEMPERATURES - Deg. Fahr.					
Feed Water	59.7	60.0	58.6	56.1	56.4
Boiler Room	102	104	105	97	92
Calorimeter	252.6	247.7	244.0	255.0	259.7
Boiler Outlet Gases	461	505	546	483	486
Flue Gas Analysis - Percent					
Carbon Dioxide - CO_2	10.0	8.6	7.3	8.7	8.8
Oxygen - O_2	7.6	9.0	12.0	10.8	10.7
Carbon Monoxide - CO	Trace	0.0	0.0	0.0	0.0
Pounds of Air per lb. Coal	17.5	20.2	23.8	20.0	19.7
Percent Excess Air	80	110	140	105	104
PROXIMATE ANALYSIS OF COAL AS FIRED					
Moisture	2.8	3.1	3.1	2.9	2.8
Ash	7.7	5.9	9.2	6.3	6.2
Sulphur	0.35	0.35	0.8	0.8	0.9
Heat Value - B.T.U. per lb.	12,180	13,070	12,000	12, 580	12,550

RESULTS OF TESTS Cont'd

	Old Comb. Chamber 8 Hr. test August 4.	New Comb. Chamber 8 Hr. Test August 12.	First 5 Hrs. of 8 hr. test August 20.	First 8 Hrs. of 24 Hrs. test Sept. 2.	24 Hr. test Sept. 2nd.
RESULTS					
Duration of Test	8 Hours	8 Hours	5 Hours	7.Hr.50Min.	23Hr. 12Min.
Total Coal Burned - lb.	5503	4650	3395	4818	14,825
Coal Burned per Hour - lbs.	688	581	679	615	639
Total Water Evaporated - lbs.	40450	38692	25336	38450	115,825
Water Evaporated per hour- lbs.	5056	4836	5067	4909	4,992
Percent Moisture in steam	1.56	1.75	1.92	1.27	1.05
Factor of Evaporation	1.177	1.175	1.174	1.182	1.184
Equiv. Evap. per hr. "F&A" 212 F.	5952	5680	5950	5803	5,911
Boiler Horsepower Developed	173-	165	173	168	171
Percent Rating of Boilers	115	110	115	112	114
Actual Evaporation per lb. coal	7.351	8.321	7.463	7.980	7.813
Equiv. " " " "	8.653	9.773	8.763	9.434	9.251
Efficiency %	69.0	72.6	70.8	72.8	71.5

HEAT BALANCE	BTU	%	BTU	%	BTU	%	BTU	%	BTU	%
Heat Absorbed by Steam	8397	69.0	9483	72.6	8503	70.8	9154	72.8	8977	71.5
Heat Loss due to Comb. of Hydrogen	637	5.2	645	4.9	655	5.5	644	5.1	648	5.2
Heat Loss due to Moisture in Coal	33	.3	38	.3	38	.3	35	.3	34	.3
Heat Loss in Dry Chimney Gases	1550	12.7	1992	15.2	2570	21.4	1900	15.1	1910	15.2
Radiation & Unaccounted For	1563	12.8	912	7.0	234	2.0	847	6.7	981	7.8
TOTAL HEAT PER POUND OF COAL	12180	100.	13070	100.0	12000	100.0	12580	100.00	12550	100.0

OBJECT:-

The object of these tests was to determine the increased efficiency of the boiler and the extent of eliminating the smoke after installing the McVay Combustion Chamber, compared to the original setting.

The first test of August 4th was run on the boiler before any change was made in the setting. The McVay Combustion Chamber was then installed August 9th and three subsequent tests made. On each test sufficient data was observed to make a complete heat balance, together with a record of the smoke and other information of interest. Sketches of the boiler setting both before and after the change are shown on Pages 88 and 89.

EQUIPMENT:-

Boiler. 150 Horsepower Horizontal Return Tubular Boiler Manufactured by the Brownell Co. of Dayton, Ohio, Type Brownell C-A-14, Shell 72" Dia x 18' - 0" long.

Stoker. American Underfeed Size No. 10. Length of retort 6' - 0", width 13 1/2", overall width of retort and tuyeres 23 1/2".

Fan. Double inlet, steel plate blower with constant speed motor. Damper in air duct is hard to operate and is not used.

Boiler Feed Pump.

The pump used on tests was a 5 1/4" 3 1/2x5" Duplex steam pump made by the Snow Pump works. This pump was brought from the University to be used on the test only. The regular method of feeding the boiler is by two tilting traps in series taking condensed steam from the factory and using city water for make up.

Weighing Equipment for Water.

The water fed to the boilers was drawn from the city mains at approximately 60 degrees Fahr. into a tank holding about 700 lbs. and resting on a set of scales. It was then emptied thru a valve into a second tank which acted as a reservoir for the boiler feed pump. At the beginning of each test the level of water in the reservoir tank was measured, then water from the weigh tank was admitted as required, and at the end of the test the water level brought to the same level as at beginning. The water weighed in the weigh tank was then the true amount fed to the boiler. At the end of each hour the water level in the reservoir tank was measured and the hourly cutoff determined by accounting for the difference in level plus the amount admitted from the weigh tank. By admitting a weighed amount of water the reservoir tank was found to hold 27 pounds per inch of depth. The water level in the boiler was marked at the beginning of each test by a string around the gage glass, and as nearly as we could control it the water was kept at that constant level. At the end of each test the water was brought to the level marked by the string. On the hourly cutoffs, if the water was not on the level of the string, an adjustment of water evaporated was made by allowing 430 lbs. of water per inch difference in level. This value was determined by calculation from the size of the boiler at this level.

Weighing Equipment for Coal.

Coal was weighed by filling three buckets at a time, weighing them on a set of scales and then dumping the coal into the stoker hopper. At the beginning of each test the hopper was filled and then brought to the samelevel at the end of each hour and at the end of the test. This set of scales was checked against a very delicate platform scale in the McDonald factory and found to weigh within one pound of each other on 100 lb. weight.

Calorimeter.

The calorimeter for determining the moisture in steam was of the throttling type, exhausting to the atmosphere. The pressure in the expansion chamber was shown by a U-tube containing water, the pressure being only about 2 inches of water. The temperature of the steam after expansion was read on a short mercury thermometer which did not project above the top of the thermometer well, hence, no steam correction need be applied. The well was kept full of cylinder oil. The sampling pipe was placed in the horizontal diameter of the 6" steam main on top of boiler and about six feet beyond the angle stop valve.

Flue Gas Analysis.

The sampling pipe was inserted thru the front boiler casting half way between the upper row of tubes and the breeching. This extended into about the center of the stream of gas. The sample was analyzed in an Orsat apparatus filled with fresh solutions furnished by the U. S. Bureau of Mines. The sample was passed in turn thru the three pipettes containing the proper solution to absorb the carbon dioxide, the oxygen and the carbon monoxide.

The difference in volume of the sample before and after passing thru one of these solutions represents the amount of gas absorbed and thus tells the proportion of that constituent in the sample being analyzed.

Pressure Gage. The boiler steam pressure was read on a test gage furnished by the University of Utah.

Barometer. The atmospheric pressure was read on a high grade mercury column barometer in the Bureau of Mines building at the University of Utah.

Thermometers. The thermometers used for boiler room temperature and feed water temperature were high grade mercury thermometers, 0 to 300 degree Fahr. scale. The thermometer for boiler room temperature was hung on a column near the boiler but not in line of direct radiation from the fire. The thermometer for feed water temperature was inserted in a well placed in a pipe tee next to the boiler feed pump. The well was packed with graphite to conduct the heat from the water to the thermometer. The temperature of the flue gas was read on an indicating differential expansion type thermometer placed in the breeching just at the boiler outlet. This indicator was set to read the same as a mercury thermometer placed along side of it in the hot flue gases just before the test of August 4th, and again before the test of September 2nd.

Draft Gage. The draft was read on an Ellison inclined gage, the indicating medium being oil. The stack draft was taken from the sampling pipe used for flue gas analysis, and to get the draft over the fire a 1/8" pipe was inserted thru the small inspection hole in the front door of the furnace.

Coal Sample and Analysis.

Once each hour a representative shovel full of coal was placed in a tub and at the end of the test the tub containing about 150 pounds of coal was dumped out on a clean place on the floor, mixed thoroughly and quartered down successively until about 15 pounds remained. This was placed in a can with a tight fitting lid and taken to the University for testing. Here it was again mixed and one quarter ground thru a coffee mill. The total moisture was determined from this size and the sample was kept in a glass jar with a tight fitting lid. One quarter of this sample was taken and ground in a mortar and pestle until all of it was passed thru a 65 mesh sieve. Samples of this fine coal were then run for moisture, ash and B.T.U. In all cases duplicate samples were run for checking the results.

The calorimeter used for the B.T.U. determinations was a new "Burgess-Parr" Pexoxide Bomb Calorimeter. The instrument was checked by running a sample of benzoic acid prepared by the Bureau of Standards and having a known calorific value. From the data observed the calorimeter was found to be accurate within one percent. The sulphur content was run on the residue from the peroxide fusion in the bomb, the sulphur being present as a sulphate It was leached out with distilled water and percipitated as Barium Sulphate.

When the B.T.U. values of the coal on the first three tests were found to be so different, a new cut of the original course samples were taken, ground down, and carefully run. In all three cases this re-cut sample checked with the original cut which proved to our satisfaction that the analysis was correct for the sample received

TEST OF AUGUST 4th.

There was no steam required from the boiler Saturday and Sunday, August 1st and 2nd, hence the fire was allowed to go out. Monday, August 3rd, it carried the usual plant load. The soot was blown from the tubes about 4 P.M. and at 4:30 P.M. the load was taken off and the fire banked during the night.

The fire was started at 6:00 A.M. August 4th, the morning of the test, and by 7:30 about 1200 lbs. of coal had been fed and there was a heavy bed of coal on the grate, the steam pressure had raised from 0 to 45 lbs. per sq. in. At this point the stoker was stopped for about twenty minutes to let the fuel bed burn down. By 7:45 the steam pressure was up to 83 lbs. which was the setting of the pop-off valve, so a valve was opened to the atmosphere and the boiler carried a heavy load until 8:30, the start of test. At the beginning of the test there was a fairly heavy fire but we called it an average size to carry the load and aimed to end with the same size, which we did to the satisfaction of all present.

Mr. Jacobs, the regular dayshift boiler attendant was placed to weigh the feed water and to also watch the speed of the stoker and conditions of fuel bed. A man from the McDonald factory was placed to weigh the coal and keep the hopper full. The writer, Mr. Duke, made all observations of pressures, temperatures, etc., and run the flue gas analysis. At noon the factory man was replaced by Mr. Mes, the morning shift fireman who then weighed the coal and controlled the stoker.

TEST OF AUGUST4, 1931.

TIME	Steam Press. Lbs.	Feed Water Temp.	Room Temp.	Calorim Temp.	Calorim Press In. Water	Flue Gas Temp.
8:30	60	60	90	250	1.50	440
8:40	60	60	91	245	1.50	450
8:50	62	60	90	250	1.75	450
9:00	66	60	90	250	2.00	440
9:10	75	61	91	253	3.00	450
9:20	76	60	93	265	3.00	460
9:30	80	60	94	257	3.50	460
9:40	83	60	95	258	3.50	460
9:50	83	59	95	260	3.75	470
10:00	83	60	98	255	3.50	470
10:10	80	60	99	255	3.25	470
10:20	77	60	99	255	3.00	470
10:30	78	60	100	255	3.00	480
10:40	78	60	101	252	3.00	480
10:50	76	60	101	254	2.75	480
11:00	72	60	101	252	2.25	470
11:10	68	60	102	250	2.00	470
11:20	67	60	103	250	2.00	460
11:30	69	60	103	250	2.25	450
11:40	71	60	103	250	2.50	460
11:50	75	60	104	250	2.50	460
12:00	75	60	104	250	2.75	470
12:10	80	60	103	256	3.25	460
12:20	80	60	103	256	3.00	470
12:30	79	60	104	255	3.00	470

TEST OF AUGUST 4, 1931.

TIME	Steam Press. Lbs.	Feed Water Temp.	Room Temp.	Calorim Temp.	Calorim Press In.Water	Flue Gas Temp.
12:40	79	60	105	255	3.00	460
12:50	80	60	104	255	3.00	460
1:00	74	60	104	251	2.50	450
1:10	74	60	104	252	2.75	450
1:20	76	60	105	250	2.50	460
1:30	79	60	104	255	3.00	460
1:40	80	60	106	255	3.25	470
1:50	80	59	106	255	3.25	470
2:00	78	59	105	252	3.00	470
2:10	80	59	106	254	3.25	470
2:20	82	59	104	255	3.25	480
2:30	83	59	106	255	3.25	480
2:40	81	59	106	255	3.00	470
2:50	78	59	106	254	2.75	460
3:00	75	59	107	252	2.25	460
3:10	74	59	108	250	2.25	450
3:20	72	59	106	250	2.00	450
3:30	71	59	107	248	2.00	460
3:40	70	59	109	248	2.00	450
3:50	69	59	108	243	2.00	440
4:00	76	59	107	250	2.50	460
4:10	80	59	108	252	3.00	450
4:20	81	59	108	254	3.00	450
4:30	81	59	108	255	2.75	450
Average 8 Hrs.	75.7	59.7	102	252.6	2.72	461

TEST OF AUGUST 4, 1931.

TIME	CO2 Percent	O2	CO	STACK DRAFT	DRAFT OVER FIRE	CONDITIONS OF FIRE
8:43	9.0			.33	.28	No smoke
8:55	11.2					Very light smoke
9:15	11.0	5.4		.32	.25	
9:45	11.4					Light smoke #1
10:05	11.6	6.8		.32	.28	Light smoke #2
10:30			#3 Smoke so stopped stoker few min.			
10:35	12.4	6.2				#2 Smoke
10:55	10.0	8.0		.32	.22	
11:13	8.0	9.0		.31	.26	No smoke
11:35	11.0					#2 Smoke
12:03	8.2					No smoke
12:35	11.0			.31	.26	Very light smoke #1
12:55	10.8	7.2				Very light smoke #1
1:15	11.2			.32	.23	#2 smoke
1:35	9.6	9.2				No smoke
1:55				.31		No smoke
2:15	10.0				.26	No smoke
2:35	8.0					No smoke
2:45	10.2					(No smoke. Closed) (insp. doors)
3:05	8.0			.30	.24	No smoke
3:15	10.0	8.0		.30	.22	#1 Smoke
3:25	9.2					No smoke
3:45	10.2					#1 Smoke
4:05	9.4	9.4				#1 Smoke
4:15				.30	.20	#1 Smoke
4:25	10.4					
Averages 8 Hrs.	10.0	7.6		.31	.25	

TEST OF AUGUST 4th, 1931.

HOUR	WEIGHT OF WATER EVAPORATED	WEIGHT OF COAL FED TO BOILER	WT. WATER EVAPORATED PER LB. COAL
1	4684	1014	4.62
2	5018	676	7.42
3	5544	507	10.92
4	4711	675	6.98
5	5329	872	6.11
6	5114	527	9.70
7	5391	630	8.56
8	4659	602	7.74
TOTAL	40450	5503	7.35

NOTE: Water evaporated is adjusted for depth in reservoir tank and water level in boiler. Weight of water evaporated per pound of coal is only an apparent figure for each hour on account of the time lag between feeding the coal and its total combustion.

SAMPLE COMPUTATIONS.

Absolute steam preassure equals the boiler gage press, plus the barometer reading referred to lbs. per sq.in.

75.7 - boiler gage pressure
12.43 equals 25.35 x .4912 equals atmospheric pres.
88.1 - absolute steam pressure

12.43 - atmospheric pressure
.10 - equals 2.72 in.water x .036 equals pressure in calorimeter.
12.53 - absolute pressure in calorimeter expansion chamber.

QUALITY OF STEAM, X equals $\frac{H \text{ plus } .47\ (t' - t) - h}{L}$

Where X equals percentage of dry steam in mixture
1.00-X " percent moisture in steam.
H " total heat content of steam at pressure in Calorimeter expansion chamber.
t' " temperature in calorimeter.
t " Temperature corresponding to pressure in calorimeter.
h " heat of the liquid at absolute pressure in steam main (same as boiler)
L " latent heat of vaporization

or X equals $\frac{1147.3 \text{ plus } .47\ (252.6-204.0) - 289.0}{895.1}$ eq. .9844

then 1 - .9844 equals .0156 or 1.56 percent moisture in steam.

The Factor of Evaporation equals the ratio of the heat required to evaporate a pound of water under actual conditions of pressure and temperature to the heat required to evaporate a pound from and at 212 deg. Fahr. The heat added per pound of water fed to boiler is H equals XL plus h-h', the notation being same as given above except h' which is the heat contained per lb. of water at temperature at which it was fed to boiler.- all heat contents being measured from that contained in water at 32 deg. F.

H equals .9844 x 881.1 plus 289.0-37.7 equals 1142.4 B.T.U.
then Factor of Evaporation - $\frac{1142.4}{970.4}$ equals 1.177, the value 970.4 being the latent heat of vaporization at 212 deg. Fahr.

The Equivalent Evaporation per hour equals the actual evaporation per hour, times the factor of evaporation, or 5056 x 1.177 equals 5952 lbs. Which means that the same heat that evaporated 5056 lbs. on our test would have evaporated 5952 lbs. "from and at" 212 deg. Fahr.

The Boiler Horse Power Developed equals the equivalent evaporation per hour divided by 34.5 or $\frac{5952}{34.5}$ equals 173.

Percent Rating of Boilers equals the horsepower actually developed divided by the horsepower rating given the boiler by the manufacturer, or $\frac{173}{150}$ equals 115 per cent.

Actual evaporation per lb. of Coal equals the total water evaporated, divided by the total weight of coal burned, or $\frac{40450}{5503}$ equals 7.351 lbs.

The Equivalent Evaporation per lb. of Coal equals the actual evaporation times the factor of evaporation or 7.351 x 1.177 equals 8.653.

The Efficiency of the Boiler equals the percentage of heat in the coal burned which was actually absorbed by the water and steam, and is found as follows: The heat units required to evaporate each pound of water was 1142.4, as given above under "Factor of Evaporation", the actual evaporation per lb. of coal was 7.351 pounds, then for each pound of coal burned 1142.4 x 7.351 equals 8397 B.T.U. were absorbed by the water and steam. Each pound of coal burned contained 12,180 B.T.U. hence the ratio $\frac{8397}{12180}$ equals 69.0 per cent is the efficiency of the boiler.

Heat Loss Due to Combustion of Hydrogen. The coal burned contains a certain percent hydrogen which burns to form water vapor and goes out with the stack gases as superheated steam. In a bomb calorimeter, the products of combustion are cooled down to room temperature, the water vapor is condensed and the heat given up hence the B.T.U. value found is referred to the heat above room temperature and when we have the products of combustion going up the stack at a high temperature we must account for the heat carried with them.

Each pound of moisture carries away enough heat to raise the temperature of the water from the room temperature to the boiling point plus the latent heat of vaporization plus the heat to superheat the steam from the boiling point to the temperature of the stack gases. This equals (204 - 102) plus 970 plus .47 (461-204) equals 1193 B.T.U. per pound of water vapor formed. For each pound of coal burned 0.533 lbs. of vapor are formed, so the heat in the moisture per lb. of coal is 0.533 x 1193 equals 637 B.T.U. and the ratio of this heat to the heat per lb. of coal gives the percent loss, or $\frac{637}{12180}$ equals 5.2 percent.

Heat Loss due to Moisture in Coal equals the same 1193 B.T.U. per pound of moisture times the weight of moisture per lb. of coal equals 1193 x .028 equals 33 B.T.U. and represents $\frac{33}{12180}$ equals 0.3 percent of the heat in the coal.

Heat Loss in Dry Chimney Gases. For each pound of coal burned there is a certain amount of gas goes up the stack, the amount depending on the weight of air used per pound of coal. This ratio of air to coal is found from the flue gas analysis, there being a certain weight of air for any given proportion of Carbon dioxide in the gases. For convenience, a curve has been plotted giving the weight of dry chimney gases per pound of coal based on the ultimate analysis of a representative sample of Utah coal. A print of this curve is given on page 37. The weight of dry chimney gases per pound of coal corresponding to 10.0 percent carbon dioxide is found to be 18.0 lbs. This amount has to be heated from the room temperature to that of the flue gases or 461-102 equals 359 degrees. The specific heat of these gases is 0.24 so the B.T.U. carried out per pound of coal burned is 18.0 x 359 x 0.24 equals 1550. This represents $\frac{1550}{12180}$ equals 12.7 percent of the total heat per pound of coal.

Radiation and Unaccounted for. The remainder of heat not accounted for in the above items as going up the stack or into the steam are termed "Heat loss due to Radiation and Unaccounted For". In any boiler there is a certain amount of heat radiated from the setting, and another portion absorbed in heating up the brick work. These cannot be measured directly, but are known to exist, and from experience they have been found to be from 3 to 6 or 8 percent depending on the initial and final temperatures of the brickwork. Another portion of heat included in this item is that which goes up the stack as unburned gases and not found in the Orsat analysis as CO. When the boiler is smoking we know that some hydrocarbons are going up the stack unburned and since our Orsat analyses do not give a continuous record, there is undoubtedly a few percent loss. The only ash removed from this type of furnace is taken out in the form of clinker and contains practically no unburned particles of fuel. Whatever heat units are lost in the ash are included in the above as "unaccounted for." For the test of August 4th the loss due to Radiation and Unaccounted For is given thus:

12,180 -(8397 plus 637 plus 1550) equals 1563 B.T.U.

or

$\frac{1563}{12180}$ equals 12.8 percent of the heat per lb. of coal.

Discussion. The percent efficiency is found to be a reasonable one for an H.R.T. Boiler fired under these conditions; the stack temperatures are as low as could be expected but the "Loss due to Radiation and Unaccounted For" are high. This high loss is partly due to the fact that the boiler had had only a banked fire all night and during the first hours of the test would absorb considerable heat: and secondly, to the fact that the first hour of the test an extra heavy charge of coal was fed and was undoubtedly more than the grate could burn completely, and much of the fuel went out of the stack as smoke. Our record shows the boiler did send out considerable smoke and the City Smoke Inspector who was watching the stack, claimed we had a No. 3 smoke most of the time until 10:30 A.M.

TEST OF AUGUST 12th.

The boiler was cooled down Saturday, August 8th to enable the men to work inside the boiler the following day and install the brickwork of the McVay Combustion Chamber. When the men finished work Sunday afternoon they made a fire and brought up a few pounds of steam pressure and then banked the fire until the following morning. The boiler carried the regular load Monday, was banked Monday night, carried the regular low load in the forenoon Tuesday and in the afternoon we opened the steam line to the atmosphere and carried a heavy load all afternoon in order to make preliminary tests on the air required, carbon dioxide, temperatures in the chamber, etc. The brickwork didn't have time to heat up to a red heat before quitting time at 5 P.M. The soot was blown from the tubes at about 4:30 P.M., so they would be clean the following day for the test.

The firemen were overly anxious to get the new brickwork heated up so the fire was started at 3:00 A. M. Wednesday, August 12th, and full steam pressure of 83 lbs. was attained by 5 A.M. Two large boxes of cocoa bean shells were brought from the factory and thrown into the furnace by hand; this took from about 6 o'clock until 8:20 to burn them up. Cocoa bean shells ignite very readily and burn with a long hot flame so the rear combustion chamber was filled with flame and by 8:30 the new brickwork installed by Mr. McVay was heated to a glowing red which was as hot as the brickwork ever became on any of the tests.

During the time from 7:30 until 8:20 the stoker was run at a slow rate to get and keep a bed of coal from 8:20 until 8:40it was speeded up so that at the beginning of the test at 8:40 there was an average size fuel bed and the test ended with approximately the same amount. Mr. Mes, the morning fireman, weighed the coal and controlled the stoker during the test and Mr. Jacobs weighed the feed water. The boiler feed pump would not speed up enough to keep the water level in the boiler up to the mark we made at the start of the test, so it was stopped to clean out the steam line and blow the oil and water out of the exhaust line. The stoker was also stopped 10 minutes to compensate for this. During the remainder of the test our limiting factor was the amount of water the pump would feed and we had to slow up somewhat on the coal feed in order to end the test with the water level in the boiler at the same line as at start.

TIME	STEAM PRESS LBS.	FEED WATER TEMP.	ROOM TEMP.	CALORIM TEMP.	CALORIM PRESS IN. WATER	FLUE GAS TEMP.	
8:40	63	60	97	247	1.50	500	
8:50	63	60	97	246	1.50	490	
9:00	64	60	98	244	1.50	490	
9:10	66	60	98	245	1.50	500	
9:20	69	60	98	246	1.75	510	
9:30	74	60	99	250	2.00	510	Water 1" low
9:40	76	60	99	250	2.25	520	
9:50	77	60	100	250	2.25	520	
10:00	78	60	100	251	2.50	530	
10:10	80	60	101	253	2.50	530	
10:20	83	60	102	252	3.00	540	Pump stopped to clean out steam line. Water 3 1/2" low
10:30	80	60	103	252	2.75	530	
10:40	81	60	103	254	2.50	520	
10:50	78	60	104	250	2.50	510	
11:00	80	60	103	251	2.75	510	
11:10	79	60	104	253	2.50	510	Closed steam to pick up water
11:20	84	60	105	256	2.75	500	Stoker & Fan stopped 10 mi
11:30	67	60	104	250	1.50	480	
11:40	67	60	105	246	1.50	500	Water 3" low.
11:50	74	60	106	248	1.75	500	
12:00	76	60	106	250	2.00	500	
12:10	76	60	105	250	1.75	500	
12:20	76	60	105	250	2.00	490	
12:30	79	60	106	251	2.25	500	

August 12, 1931.

TIME	STEAM PRESS LBS.	FEED WATER TEMP.	ROOM TEMP.	CALORIM TEMP.	CALORIM PRESS IN WATER	FLUE GAS TEMP.	
12:40	77	60	105	250	2.25	500	Water 1"low
12:50	77	60	105	250	2.25	500	
1:00	76	60	105	250	2.00	500	
1:10	70	60	104	248	2.00	490	
1:20	68	60	104	248	1.50	470	
1:30	62	60	104	243	1.00	450	Sliced clinker.
1:40	58	60	105	240	1.00	470	
1.50	66	60	104	242	1.50	480	
2:00	68	60	105	244	1.50	500	
2:10	73	60	104	248	2.00	510	
2:20	76	60	108	250	2.00	510	
2;30	75	60	107	250	2.00	510	
2:40	73	60	107	250	1.75	510	
2:50	70	60	106	246	1.75	510	
3:00	76	60	106	247	2.00	510	
3:10	80	60	106	248	2.50	530	
3:20	76	60	105	250	2.00	520	
3:30	66	60	106	245	1.50	510	
3:40	62	60	105	242	1.00	500	Water 3/4"high
3:50	60	60	105	238	1.00	510	
4:00	64	60	104	240	1.25	510	
4:10	68	60	105	245	1.50	510	
4:20	69	60	108	242	1.50	510	
4:30	70	60	106	245	1.50	510	
4:40	71	60	106	246	2.00	500	Water on line.
Average 8 Hrs.	72.3	60	104	247.7	1.89	505	

August 12, 1931.

TIME	PERCENT CO2	PERCENT O2	STACK DRAFT	DRAFT OVER FIRE	CONDITION OF FIRE
8:45	8.4		.34	.16	No smoke-back part of insp. doors open
9:05	9.0	8.8			
9:25	10.0		.32	.24	#1 smoke
9:45	11.0		.32	.20	#1 smoke-ins.door closed.
10:05	11.4	6.2			#1 smoke
10:15					#2 smoke-opened ins. doors.
10:25	9.0				#1 smoke
10:45	8.8		.30	.25	No smoke
11:05	10.2	8.2			#2 smoke
11:24	4.0				Very clear-stoker & fan stopt.
11:45	9.0	9.8	.32	.22	#1 smoke
12:05	7.8		.34	.24	Very clear.
12:25	9.6				#1 smoke
12:45	8.6		.34	.22	Very clear.
1:05	8.0	10.8			Very clear.
1:25	7.2				Very clear-closed damper for ten min. & steam press dropt.
1:45	8.2				Very clear.
2:05	9.0	10.0	.34	.25	#2 smoke-back air hole closed.
2:25	8.4				Very clear.
2:45	6.6				Very clear.
2:55	10.2				#2 smoke
3:15	7.0		.33	.22	Very clear.
3:45	7.0				(#1 smoke-stepped stoker up
4:05	8.2				-(2 notches for ten minutes.
4:15	9.0				#2 smoke
4:35	8.8		.33	.25	#1 smoke
Averages 8 Hrs.	8.6	9.0	.33	.22	

HOUR	WEIGHT OF WATER EVAPORATED.	WEIGHT OF COAL FED TO BOILER	WT. WATER EVAPORATED PER LB. COAL.
1	4797	918	5.23
2	5931	581	10.20
3	5157	516	10.00
4	4202	551	7.63
5	5181	456	11.38
6	4383	520	8.43
7	4532	552	8.22
8	4509	556	8.11
TOTAL	38692	4650	8.32

NOTE:- Water evaporated is adjusted for depth in reservoir tank and water level in boiler. Weight of water evaporated per pound of coal is only an apparent figure for each hour on account of the time lag between feeding the coal and its total combustion.

DISCUSSION. The efficiency on this test is found to be 72.6 percent which is a gain of 3.6 percent over the test of August 4th with the original setting. This gain was due primarily to the improvements in the setting, giving longer flame travel and better mixing of the gases, hence, more complete combustion of the volatile hydrocarbons. Some of the gain is due to the boiler being hotter at the start which would mean a smaller portion of the heat being absorbed by the brickwork. Our record of the smoke shows the stack to be clear and all who were watching the test agreed that the coal was being burned without the emission of smoke.

The percent carbon dioxide on this test was lower than on the previous test on account of the additional air admitted thru the preheating ducts into the McVay chamber. The reason for the flue gas being at higher temperature is that the gases are kept away from the boiler shell, going thru the hot brickwork and thus enter the tubes at a higher temperature.

The coal used on this test showed a higher calorific value than the coal used August 4th, even though both tests were using from the same car load. The following explanation can be made which to some of us seemed reasonable enough to account for all the difference. As the carload was dumped thru holes in the top of the bin the finer coal would remain in the center and the coarser coal roll to the outside. The coarse coal is cleaner and has undergone less surface oxidation so would have a higher heat value. The test of August 4th was using coal from the center of the bin, while the test of August 12th was using from the end and getting coarser coal. The analyses show the first sample to be higher in ash content with a corresponding lower B.T.U. per pound.

TEST OF AUGUST 20th.

The feed water pump was overhauled and adjusted so that it would run considerably faster than on the previous test and would not limit the capacity of the boiler. The regular plant load was carried during the first three days of the week, this test being run on Thursday. The soot was blown from the tubes Wednesday at about 4 P.M.

The fire was started Thursday morning at 5:45 o'clock and full steam pressure of 83 lbs. was up at 7:25. The valve was opened to blow steam to the atmosphere at 7:55 so the boiler carried the full test load from then until 8:20, the time of beginning. Mr. Mes fired the boiler during the warming up period as well as thru the whole test. At the beginning of the test there was a much heavier bed of fuel on the grate than on the previous tests. During the test the clinker accumulated several times and was barred from the tuyeres and thrown over the dead plates. In doing so considerable combustible was also thrown over and at the end of the test the pile of coal directly on the tuyeres was considerably less than at beginning. Due to the combustible on the side plates it was very difficult to judge the actual difference in amount of fuel in the furnace at the end and at the beginning. After making the calculations and the heat balance, we were forced to the conclusion that the difference in fuel bed was an appreciable portion of the error of the test.

August 20, 1931.

TIME	STEAM PRESS	FEED WATER TEMP.	ROOM TEMP.	CALOR TEMP	CALOR PRESS	FLUE GAS TEMP.	
8:20	78	57	98	248	2.50	550	Brick dull red.
8:30	76	57	98	246	2.00	550	
8:40	70	57	98	245	2.00	540	
8:50	68	57	99	245	2.00	540	
9:00	74	57	100	247	2.25	550	
9:10	74	58	100	247	2.25	550	
9:20	76	58	101	247	2.50	550	Water on line.
9:30	73	59	101	247	2.25	450	
9:40	71	59	102	244	2.00	540	
9:50	69	59	103	245	2.00	540	
10:00	66	59	103	243	1.50	540	
10:10	65	59	104	242	1.75	560	
10:20	67	59	105	240	1.50	550	Water 2"high.
10:30	65	59	104	240	1.50	540	
10:40	70	59	104	240	2.00	540	
10:50	74	59	104	244	2.50	540	
11:00	76	59	105	245	2.50	540	
11:10	70	59	107	245	2.00	540	
11:20	72	59	108	245	2.25	560	Water 1 1/4" high
11:30	72	59	107	245	2.25	540	
11:40	75	59	108	246	2.50	530	
11:50	77	59	110	244	2.75	530	
12:00	80	59	110	248	3.00	540	Cleaned fire.
12:10	83	59	111	245	3.25	580	Brickwork getting white.
12:20	82	59	111	255	3.25	590	Water level 1/2 "low

August 20, 1931.

TIME	STEAM PRESS	FEED WATER TEMP.	ROOM TEMP.	CALOR TEMP.	CALOR PRESS	FLUE GAS TEMP.	
12:30	77	59	110	250	2.50	560	
12:40	70	59	112	244	2.00	550	
12:50	64	59	111	238	1.50	530	
1:00	56	59	111	235	1.00	520	Cleaned fire.
1:10	60	59	112	234	1.25	570	
1:20	62	59	114	234	1.25	540	Water level on line.
1:30	62	59	112	235	1.50	530	
1:40	66	59	114	238	1.75	530	
1:50	66	58	115	237	1.75	540	
2:00	64	58	113	235	1.50	550	
2:10	65	58	112	235	1.75	560	
2:20	64	58	112	235	1.50	540	
2:30	62	58	114	235	1.50	540	
2:40	60	58	115	235	1.50	530	
2:50	61	58	114	235	1.50	530	
3:00	65	58	115	236	1.75	580	
3:10	66	58	112	238	1.75	540	
3:20	70	58	112	236	2.00	530	Water level on line.
3:30	72	58	110	240	2.25	540	
3:40	70	58	110	240	2.00	550	
3:50	67	58	112	238	1.75	560	
4:00	65	58	114	238	1.50	540	
4:10	62	58	113	236	1.25	530	
4:20	62	58	113	235	1.25	530	Water level on line.
Averages 8Hrs.	69.0	58.4	108	241.2	1.95	545	
First 5 Hrs.	71.3	58.6	105	244.0	2.12	546	

August 20, 1931.

TIME	PERCENT CO2	O2	CO	STACK DRAFT	DRAFT OVER FIRE	CONDITION OF STACK
8:20	Start - Fire Bed up to top of doors in center.					
8:35	7.2					No smoke
8:55	8.0	12.2	0.0			#1 smoke
9:15	7.4					No smoke
9:35	7.8			.33	.21	#1 smoke
9:55	7.4	12.0	0.0			Clear
10:25	7.2				.22	Very clear
10:45	7.2					Very clear
11:05	7.2					Very clear
11:25	7.2					Very clear
11:45	8.0	12.0	0.0			#1 smoke
12:05	8.0					
12:25	6.2					Very clear
12:45	6.8					Very clear
1:15	6.6					Very clear
1:25	7.4			.33	.22	Clear
1:45	6.2					Very clear
1:55	8.0	11.4	0.0			#1 smoke
2:25	6.0					Clear
2:45	5.8					Very clear
3:05	6.6					Clear
3:25	8.2			.33	.23	#1 smoke
3:45	6.4					
4:05	6.0					Back air hole open all day
4:20	End of Test - Fire not so high in middle. Is spread out more and burned more to coke and ash					
AVERAGE 8 Hrs.	7.1	12.1	0.0	.33	.22	
First 5 Hrs.	7.3	12.0	0.0	.33	.22	

HOUR	WEIGHT OF WATER EVAPORATED	WEIGHT OF COAL FED TO BOILER	WT. WATER EVAPORATED PER LB. COAL.
1	4935	706	6.98
2	4571	763	6.00
3	4954	648	7.65
4	5651	613	9.22
5	5235	665	7.87
6	5384	548	9.82
7	5035	422	11.93
8	5167	352	14.70
TOTAL	40922	4717	8.67
First 5 Hrs.	25336	3,395	7.46

NOTE:- Weight of water is adjusted for depth in reservoir tank and level in boiler.

DISCUSSION: As soon as the results were calculated and the heat balance made, showing more heat to have been taken out of the boiler than was contained in the fuel burned, we had to admit that errors had crept into the data. The complete data are given here and results calculated to show the approximate efficiency and distribution of heat but these results are not to be relied upon to the same extent as those of the tests on each of the other days.

There are three sources of error which may have affected the results and each one will be discussed separately with the note at beginning that neither of the three seem possible alone to account for the big difference, hence, at least two, and maybe three, causes are present to give erroneous results. The source of error are:

1. As stated previously, there was an extra heavy bed of fuel at the beginning of the test and the fire at the end was in such a state as to make it very difficult to estimate its size compared to the beginning. From the tabulation given above of the fuel burned per hour, one can readily see how the amounts dwindled down at the end of the test and the figure representing the amount of water evaporated per pound of coal, although being only an apparent value, is a value that would be impossible to sustain as an average figure.

We must conclude therefore, that part of the water evaporated near the end of the test was evaporated at the expense of heat previously put in, either by diminishing the size of the fuel bed or by drawing back heat units previously stored in the brick work. To show the possibility of this, at the end of the 24 hour test of September 2nd, with but a low fire, the stoker was stopped and 2100 pounds of water were evaporated without adding a pound of fresh coal.

2. It may have been possible for some coal to have been weighed and fed to the boiler and yet the weight not entered on the data sheet.

3. The coal sample as quartered, cut down and taken to the University for testing may not have been a really representative sample. The coal used was brought in truck loads from a local yard. All the tests were run on coal from the same mine. This coal was a fairly coarse grade of slack but contained many pieces of bone. All the men present noticed the presence of this bone and the fireman had considerable trouble barring clinkers to keep the tuyeres clean enough to carry the load. It may have been possible in picking the shovel of coal each hour for the sample pile to have gotten more pieces of this bone coal than was really representative of the lot of coal burned. Likewise in cutting down the sample to the laboratory size an oversupply of bone may have remained. The analysis shows an extra high percentage of ash and a correspondingly low B.T.U. content but enough checks were run to satisfy us that the analysis was correct for the sample received at the University.

The following heat balance is given to show how the total heat accounted for is greater than that contained in the fuel, but note also the percentage of heat absorbed by the steam is still only 72.7 percent of the total of 13,587 B.T.U's. The heat loss due to radiation and unaccounted for, is assumed, but is taken as the minimum that could possibly be expected in practice.

HEAT BALANCE FOR FULL 8 HR. TEST AUGUST 20th.

	B.T.U.	Percent
Heat absorbed by steam	9875	72.7
Heat loss due to combustion of Hydrogen	654	4.8
Heat loss due to moisture of coal	38	.3
Heat loss in dry chimney gases	2620	19.3
Radiation and unaccounted for	400	2.9
	13587	100.0

Heat per lb. of coal 12,000

24 HOUR TEST SEPTEMBER 2nd.

A smoke inspection device was installed to enable the fireman to observe, from the boiler room floor, the condition of the gases leaving the boiler. This consisted of a mirror and tube on one side of the breeching which permitted looking thru at a light placed in a tube on the opposite side. When the stack was clear the light shown brightly but as soon as the gases became smokey the light went dark.

The boiler carried the regular plant load during the first two days of the week, this test being run on Wednesday. The soot was blown from the tubes on Tuesday about 4 P.M. Castle Gate coal was delivered in trucks from the yards of the Bamburger Coal Company and seemed to be a clean coarse grade of slack.

In starting up the boiler before this test complete records were kept of the coal burned, water fed to boiler, steam pressure, condition of smoke, etc., The fan was started at 5:20 A.M. and the fire cleaned. The stoker retort was just level full of coals which readily blazed up when the fan was started. The stoker was started at 5:25 and 690 lbs. of coal were fed from then until 6:25 A.M. the second hour 433 lbs. of coal were fired, and the third, 587, which gave a total of 1710 lbs. of coal burned before the start of the regular test at 8:30 A.M. The steam pressure was zero at 5:20, 5 lbs. at 6:10, 10 lbs. at 6:20 and 35 lbs. at 6:30, at which time the valve was opened to give a steam load on the boiler. The pressure averaged 60 lbs. for the next two hours. The evaporation from the boiler was as follows:

1st hour	0 lbs.
2nd hour	1720 "
3rd hour	4331 "
Total 3 hrs	6051 lbs.

During these three hours, observations of the smoke were made at regular intervals, and out of 17 readings, 12 were "no smoke", 4 were #1, and 1 was #2; showing that even in the early morning, starting up from a banked fire the furnace with the McVay Combustion Chamber could be run without smoke.

Mr. Mes, the regular morning fireman, started the fire and tended it until 7:30 then Mr. Jacobs, the regular day-shift fireman tended it until 7 P. M. Mr. Mes again operated from 7:00 P.M. until midnight, when Mr. John T.

Caley, a former fireman at the plant, came on shift and worked until 7:15 A.M., when he was relieved by Mr. Jacobs who started the test and also made the cutoff at the end of the first eight hours.

Just before the beginning of the test at 8:30 A.M., the fuel bed was burned down to a fairly small size and the depth noted as about two thirds up the door way. The dead plates were scraped off clean and those of us concerned made as good a mental picture as possible of the size and condition of the fuel bed. Near the end of the first 8 hour run, the fuel bed was again burned down to enable us to again approximate the size, and end with the same size fire as when we started. The stoker was stopped at 4:15 P.M. and by 4:20 the size of fuel bed looked nearly the same as at start. The fireman scraped out all the clinkers and by the time he had finished at 4:30 we could see clearly that the size of bed left was smaller than when we started, so 4:20 was taken as the time when the fire was the same as at start.

The fire was cleaned again between 11 P.M. and midnight, getting a big pile of clinkers, much of which had fused into a dense slag. After running 22 or 23 hours we could see that the coal remaining in the bin from which we had been firing, would not last for the full 24 hours, and there seemed to be such a big apparent difference between this and the coal in the main bin we agreed to stop the stoker as soon as all the coal was fed and then end the test at the time the fuel bed had burned down to the same size as it was at the start. Thus the stoker was stopped at 7:25 A.M. and the fire closely watched while it burned down. The clinker on the dead plates seemed to contain no combustible so the pile on the retort only needed to be estimated. At 7:42 all of us who saw the start were agreed that the fuel bed was as near the same size as could be determined so a cutoff was made on the water, and the test stopped. The level in the boiler was kept on the line of start by regulating the speed of the boiler feed pump.

September 2n, 1931.

TIME	STEAM PRESS LBS.	FEED WATER TEMP.	ROOM TEMP.	CALOR. TEMP.	PRESS IN. WATER	GAS TEMP.	
A.M.							
8:30	60	56	90	248	1.00	480	Water level on line.
8:45	68	56	90	250	1.75	480	Checked flue gas thermometer.
9:00	74	56	90	255	2.00	480	
9:15	78	56	92	260	2.50	480	
9:30	73	57	92	258	2.75	480	Water level on line.
9:45	82	57	91	264	3.00	480	
10:00	76	57	94	260	2.75	480	
10:15	86	57	94	260	3.00	490	Popping off, water 1/2"high
10:30	74	57	94	260	1.50	490	
10:45	63	56	95	256	1.00	480	
11:00	66	56	93	256	1.00	480	
11:15	58	56	94	246	0.50	470	
11:30	58	56	96	250	0.50	470	Water on line
11:45	60	56	96	245	0.50	480	
12:00	72	56	97	258	1.50	480	
12:15	72	56	96	258	1.50	480	
12:30	69	56	98	258	1.25	490	Water on line
12:45	70	56	100	255	1.50	490	
1:00	68	56	98	255	1.25	490	
1:15	67	56	100	253	1.00	490	
1:30	69	56	100	255	1.25	490	Water on line
1:45	65	56	99	255	1.00	480	
2:00	76	56	100	255	2.00	500	
2:15	80	56	100	260	3.00	500	
2:30	74	56	100	258	2.50	490	Water on line
2:45	70	56	100	255	2.00	500	
3:00	68	56	102	253	2.00	500	
3:15	70	56	104	253	2.25	510	
3:30	82	56	102	258	3.50	510	Water on line
3:45	62	56	102	255	1.50	480	
4:00	55	56	104	248	1.00	480	
4:15	58	56	103	256	1.00	470	
4:30	40	56	103	250	0.00	410	Water on line
Average 8 Hrs.	68.6	56.1	97	255.0	1.66	483	

September 2, 1931.

TIME	PERCENT CO2	O2	CO	STACK DRAFT	DRAFT OVER FIRE	TEMP FIRE	TEMP Curtain WALL	SMOKE NUMBER
8:30	Start-fire clean on sides Center piled 2/3 up door							0
8:35	9.4						Too low	0
8:50							for	1
9:05	7.2	13.0	0.0				reading	0
9:20				.40	.21			1
9:30								1
9:40	9.8							2
9:55								0
10:10	9.2							0
10:35	8.6							0
10:45								0
11:05	8.2	11.8	0.0					0
11:20				.39	.22			0
11:35	7.2							0
11:50							Dull red	0
12:05	8.2							0
12:35	8.8							0
12:50			Brick not white yet			2700	Flame 1670	1
1:05	9.2	10.2	0.0	.38	.18			1
1:20								0
1:35	7.0							0
1:55								2
2:05	11.0	8.4	0.0					1
2:20				.39	.24	2700	Flame 1740	0
2:35	9.0							1
2:50							Brick pier 1725	1
3:05	11.6							2
3:20								1
3:35	6.0	Barred clinkers just before sample						0
3:50				.39	.23			
4:05	8.8							
4:15		Stopped stoker 15 min.-cleaned fire 4:15 to 4:28						
Average 8 Hrs.	8.7	10.8	0.0	..39	.22	2700	1710	0.5

(Fire about same as at start, if any difference is a little smaller - use outoff at 4:20 to get same size fuel bed as at start)

September 2, 1931.

TIME	STEAM PRESS LBS.	FEED WATER TEMP.	ROOM TEMP.	CALOR. TEMP.	CALORIM PRESS IN. WATER	FLUE GAS TEMP.	
P.M.							
4:45	50	56	102	248	0.50	440	Line to atmos-
5:00	80	56	102	264	3.25	480	phere close 30 m
5:15	72	56	101	264	2.25	490	
5:30	76		100	266	2.25	490	Water 1/2" low.
5:45	76		100	261	1.75	490	
6:00	76		100	261	2.50	490	
6:15	76	58	100	262	2.00	500	Water 1/2"high
6:30	74	58	100	261	2.25	490	
6:45	72	54	90	261	1.50	490	
7:00	60	58	92	258	1.25	490	Water 1" high.
7:15	66	58	98	258	1.75	495	
7:30	74	58	98	261	2.50	500	Water 3 1/2" high
7:45	76	58	98	263	3.50	510	
8:00	87	58	92	267	3.00	520	
8:15	82	58	92	266	3.25	500	Water 1" high.
8:30	72	60	92	262	2.00	490	
8:45	60	60	90	262	1.25	490	Water 1" high.
9:00	58	58	90	2 59	1.00	485	
9:15	64	58	90	258	1.50	480	
9:30	74	58	90	262	1.50	495	Water 1 1/2" high
9:45	76	56	90	266	2.25	490	
10:00	70	56	90	260	1.75	485	
10:15	80	56	92	263	3.00	490	Water 1/2" low
10:30	70	56	90	264	2.00	490	
10:45	60	56	88	260	1.00	490	
11:00	58	56	88	258	1.00	490	
11:15	70	56	86	260	2.00	550	
11:30	68	56	90	262	1.00	500	Water 1/2" high
11:45	60	56	90	256	0.50	480	
12:00	60	56	90	255	0.50	480	Pulled clinker.
12:15	70	57	90	262	2.25	510	
12:30	70	57	90	266	2.25	490	Water on line.

September 2, 1931.

TIME	PERCENT CO2	O2	CO	STACK DRAFT	DRAFT OVER FIRE	TEMP. FIRE	TEMP. CURTAIN WALL	SMOKE NO.
4:35	8.0							0
5:00	8.2							0
5:20								1
5:45	8.0			.36	.22			
6:05						2600	1630	
6:15	8.0			.42	.34			0
6:45								1
7:30						3200	1800	2
8:00	6.0							0
8:30	(Broke Burrell Orsat)			.43	.29			0
9.45						2875	Bel.1600	
10:00								1
10:15				.46	.22			
10:40						2875		
11:00								0
11:45								0
12:10				.42	.14			0
12:30								2

September 2, 1931.

TIME	STEAM PRESS LBS.	FEED WATER TEMP.	ROOM TEMP.	CALOR. TEMP.	CALORIM PRESS IN. WATER	FLUE GAS TEMP.	
AM							
12:45	82	57	89	268	3.25	500	
1:00	78	57	88	269	2.50	490	
1:15	76	57	89	268	2.25	490	
1:30	78	57	86	270	2.50	490	Water on line.
1:45	72	57	88	266	2.00	480	
2:00	76	57	88	265	2.25	470	
2:15	72	57	88	263	2.00	480	
2:30	80	57	87	269	2.75	490	Water on line.
2:45	70	57	86	267	1.75	510	
3: 00	74	57	86	264	2.25	490	
3:15	66	57	86	262	1.25	480	
3:30	70	57	85	259	2.00	470	Water 1/2" high
3:45	73	57	85	265	2.25	480	
4:00	66	57	85	263	1.50	500	
4:15	68	57	84	263	1.50	480	
4:30	68	57	85	260	1.75	480	Water on line.
4:45	69	56	85	258	1.75	470	
5:00	66	56	85	260	1.50	480	
5:15	65	56	82	261	1.50	450	
5:30	70	56	84	263	1.75	460	Water on line.
5:45	70	56	85	263	2.00	490	
6:00	71	56	85	262	2.25	480	
6:15	70	56	85	262	1.75	480	
6:30	68	56	85	260	1.75	480	Water on line.
6:45	70	56	86	266	2.00	490	
7:00	63	56	85	260	1.25	480	
7:16	70	56	85	264	1.50	490	Stoker stopt. 7:25
7:30	65	56	85	261	1.50	490	
7:40	58			262	0.50	480	
7:42	End of Test						Water on line.
Averages							
16 hrs.	70.3	56.6	90	262.3	1.88	488	
24 Hrs.	69.5	56.4	92	259.7	1.81	486	

September 2nd, 1931.

TIME	PER CENT CO2	02	Co	STACK DRAFT	DRAFT OVER FIRE	TEMP. FIRE	TEMP. CURTAIN WALL	SMOKE NUMBER
A.M.								
12:50	8.8 Hays Orsat							1
1:05				.43	.18	2660	Flame 1725	1
1:20	11.4							2
1:50	9.8							1
2:20	9.8							1
2:50	8.6						Brick 1640	0
3:00								0
3:20	10.6							1
3:50	8.2							0
4:20	8.6							0
4:35						2550	Brick 1690	0
4:50	9.2							0
5:20	8.0							0
5:35				.30	.18			0
5:50	9.0							0
6:20	9.2							0
6:35				.30	.21			0
6:50	8.4			.32		2650	Brick 1675	0
7:20	10.2							1

7:42 End of test. Stoker stopped 7:25 to 7:42- 17 minutes. Coal piled on burned down to as near same size at start as three of us could determine. No combustible left on dead plates. Clinker not pulled until after end of test.

Averages

	CO2	02	Co	STACK DRAFT	DRAFT OVER FIRE	TEMP. FIRE	TEMP. CURTAIN WALL	SMOKE NUMBER
16 hrs	8.8			.38	.22	2770	1680	0.5
24 hrs	8.8	10.7	0.0	.38	.22	2750	1660	0.5

4:30 A.M. - draft in air hole at back - .20 inches.
4:30 A.M. - draft in back cleanout door - .38 inches.

September 2nd, 1931.

HOUR	WEIGHT WATER EVAPORATED	WEIGHT COAL FED TO BOILER	WEIGHT WATER EVAPORATED PER LB. COAL	
1	4300	680	[illegible].32	
2	4504	558	8.07	
3	5064	580	8.72	
4	4497	664	6.78	
5	5154	711	7.25	
6	5049	691	7.31	
7	5524	491	11.26	
8 (50 min.)	4358	443	9.83	
First 8 hrs.	38450	4818	7.98	
9 (1hr.10m.)	4811	662	7.27	(Cleaned Fire-)
10	4743	603	7.87	
11	4996	843	5.93	
12	6135	591	10.37	
13	4946	613	8.07	
14	4963	592	8.40	
15	4365	583	7.48	
16	4514	624	7.23	(Cleaned fire.)
17	5357	809	6.63	
18	5300	680	7.80	
19	5435	809	6.72	
20	5481	765	7.17	
21	4923	680	7.24	
22	5098	595	8.58	
23 (1hr.12m.)	6306	558	11.30	
Last 16 hrs	77,375	10,007	7.73	
24 Hrs.	115,825	14,825	7.81	

NOTE:- Water evaporated is adjusted for level in reservoir tank and level in boiler gage glass.

DISCUSSION.

The efficiency on this test is found to be 72.8 percent for the first 8 hrs. and 71.5 percent for the full 24 hours. This shows a gain of 3.8 percent over the comparative 8 hour test run August 4th on the original setting. All the results check out so consistently with the test of August 12th that it seems we can rely upon the accuracy of the data. The fact that on the last 16 hours of the test the evaporation per lb coal was a little lower than on the first 8 hours rather surprised us, but shows that the three hours used in warming up the boiler on the morning of September 2nd were practically sufficient to bring the setting up to an even heat. There are two causes which help to account for the drop in efficiency, the first being that the clinkers were pulled twice during the last 16 hours and not pulled at all on the first 8. It takes about ten minutes to pull the clinkers and during this time the firing door is open with a big inrush of cold air to cool off the boiler setting. The second cause is that of crowding the stoker beyond its capacity during part of the last 16 hours. On all our tests the results seem to show that the stoker does its best work when burning from 550 to 700 pounds of coal per hour and whenever this is exceeded there must be some loss up the stack in unburned gases. During the last 16 hours we find three hours when 800 lbs. or more were fed to the furnace and the resulting efficiency is undoubtedly lower than it would have been if we could have kept a constant feed of 700 lbs. or less.

CONCLUSION.

1. Gain in Efficiency.

The test shows that for this particular boiler a gain in efficiency of from 3 to 4 percent was obtained by installing the McVay Combustion Chamber. It might be stated, however, that the original setting at the McDonald plant gave more combustion space and longer flame travel than the average boiler in the Salt Lake District, so it would be reasonable to expect that on installations which now have a shorter flame travel and burn with a dense black smoke, a greater efficiency could be obtained by using the McVay setting.

2- Smoke.

Observations on these tests show that the furnace really burned the coal without smoke. The rate of combustion was at least as high as the average winter load so with the proper attention on the part of the fireman the smoke problem seems to be solved for this plant. Even while starting up the boiler in the morning the stack was kept clear.

3- Need of Long Flame Travel.

An observation hole was made in this setting through which we could watch the progress of burning and it was very instructive to see the flame come over the bridge wall as a black smoking mass, then as it mixed and traveled farther through the McVay Chamber the black particles burned and just beyond the tip of the flame the gases were as clear as if we had been burning gaseous fuel. It was very apparent that our Utah coal was a long flame fuel, and we needed the extra time, turbulence and temperature as furnished by this setting to completely burn it.

4- Temperature in Chamber.

From the observations in the McVay Chamber with an optical pyrometer we found the temperature to be about 1700 degrees Fahr. This is well above the ignition temperature for the volatile hydrocarbons in our coal and on the other hand is not high enough to be destructive to the fire brick used in the setting, hence the life of the brick work in the rear chamber should be from 10 to 15 years.

5. Chamber as a Means of Storing Heat.

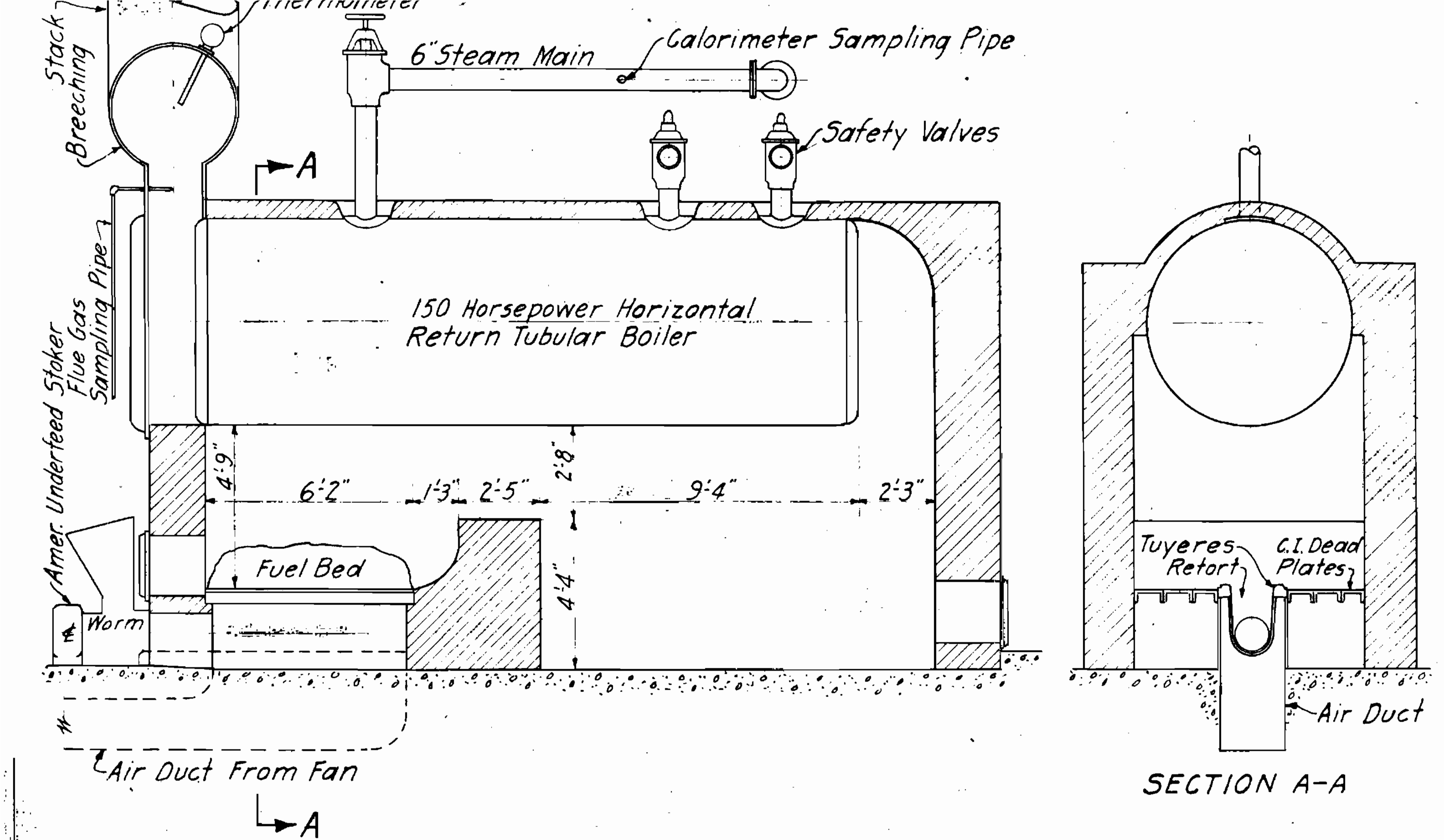
Due to the additional number of brick in this setting and the increased temperature of the brick in the back end of the boiler, more heat is stored in the setting which acts as a reservoir to help produce steam on the peak demands, helps to keep up steam longer during the night and enables the fireman to get up steam pressure quicker in the mornings. The operators at the plant say they get up steam more rapidly in the mornings now than before the change and estimate it takes 500 lbs. less coal to do so.

AUTHOR'S COMMENT- May 13, 1932.

I visited the McDonald plant recently to inquire how the operators felt toward the McVay Setting after using it all winter.

The Chief Engineer and Fireman are very enthusiastic in their praise of the setting and say they wouldn't have it removed for anything. They state that there has been an actual fuel saving of about 15 percent, besides eliminating the smoke. There has been considerably less accumulation of fine and fly ash back of the bridgewall and in place of having to blow soot out of the tubes two or three times a week as formerly, now they only have to blow the tubes once every four or five weeks. The brickwork in the McVay Chamber shows no sign of deteriorating. It is now easier to bring up steam after a banked fire, and the steam pressure holds up much longer after the stoker is stopped. This is attributed to the large reservoir of heat stored in the additional brickwork.

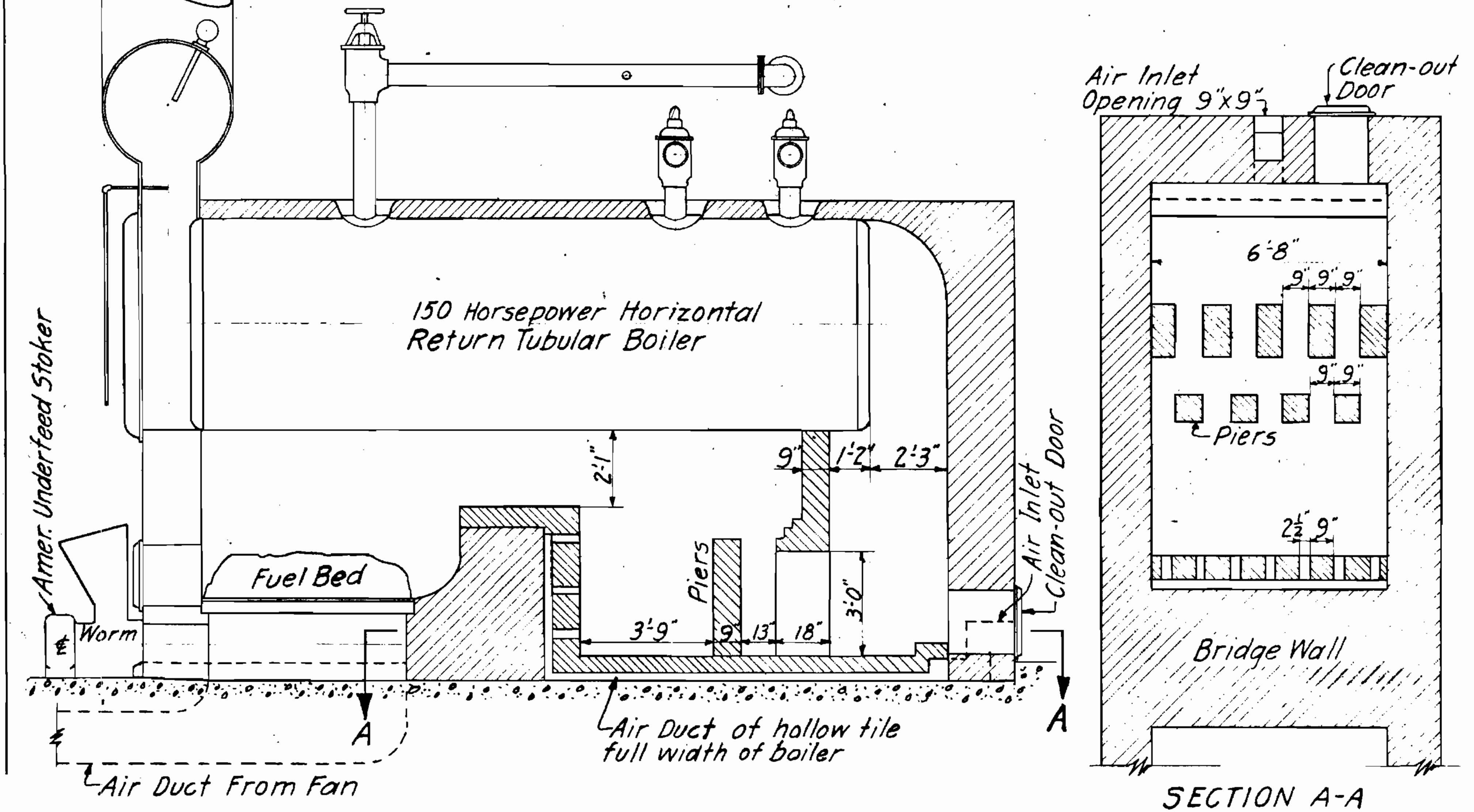
The city smoke inspector also states that the Mc Donald Plant was formerly a persistant violator of the smoke ordinances, but during the past winter there has been no smoke whatever, except a short gust once in a while when the fire was being cleaned.



BOILER SETTING AT
M^c DONALD CHOCOLATE CO.
PRIOR TO INSTALLING THE
M^c VAY COMBUSTION CHAMBER

SCALE ¼" = 1'-0"
SEPT. 17, 1931

DRAWN BY
Otto Duke



BOILER SETTING AT
M^c DONALD CHOCOLATE CO.
SHOWING THE
M^c VAY COMBUSTION CHAMBER

SCALE ¼" = 1'-0"
SEPT. 17, 1931

DRAWN BY
Otto Duke

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